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On-farm case study of greenhouse gas emissions for beef enterprises

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Abstract

In response to climate change, research is being undertaken to understand the on-farm greenhouse gas (GHG) emissions for agricultural systems and investigate options farmers may have for mitigating or offsetting emissions. In this study a Life Cycle Assessment (LCA) framework is used to determine both on-farm GHG emissions and the overall 'cradle-to-farm gate' emissions attributed to beef production. The total on-farm emissions for the two properties were 2,984 t CO2-e/yr (or 1.93 t/livestock unit) for the 634-cow enterprise turning off weaner cattle at Gympie and 5,725 t CO2-e/yr (or 1.70 t/livestock unit) for the 720-cow enterprise turning off finished steers in the Arcadia Valley. The on-farm emissions are largely attributable to enteric methane emissions from the beef herd. The overall 'cradle-to-farm gate' GHG emissions associated with enterprise products were 3,145 t CO2-e/yr at Gympie and 7,422 t CO2-e/yr in the Arcadia Valley, with the additional emissions coming from off-farm inputs (fuel for farm vehicles and earth moving equipment, electricity, supplementary feed, agricultural chemicals, farm services) and additionally, for the Arcadia Valley enterprise, from purchased store steers. The carbon footprint of beef products at the farm gate ranged from 15.8-23.4 kg CO2-e/ kg live weight at Gympie and 11.6-16.5 kg CO2-e/ kg live weight in the Arcadia Valley. The ability to off-set on-farm emissions through reforestation varied between the two locations, with predicted biosequestration rates of 19.3–34.7 t CO2-e/ha/yr at Gympie (rainfall 1200 mm/year) from eucalypt plantation and 1.5–9.8 t CO2-e/ha/yr in the Arcadia Valley (rainfall 600 mm/year) through reforestation from a combination of Brigalow regrowth, leucaena and environmental eucalypt plantings. The area that would need to be reforested to off-set on-farm emissions would be 86-155 ha at Gympie (7-13% of the holding) and 629-4,108 ha in the Arcadia Valley (9-60%). If carbon sequestration could be achieved at the higher end of the rates nominated, a significant proportion of on-farm emissions could be off-set by sequestration in timber with minimal impact on beef production. However, at the lower end of the forest sequestration range, the required level of land use change would reduce the carrying capacity, and hence beef production, especially at the Arcadia Valley site.

Executive Summary

The objective of this project was to produce two case studies of the 'carbon footprint' of beef production in northern Australia that will:

- Provide understanding of the net on-farm greenhouse gas emissions (GHG) of two example production systems;
- Assist in communication with producers and industry on net emissions and mitigation potential on farm; and
- Provide datasets of on-farm greenhouse gas emissions and sequestration potential, and some data on water use, for further analysis by MLA to inform planning for future research investment.

This report investigates the GHG emissions and water use of two beef enterprises - a south eastern Queensland breeding enterprise selling weaners, run on a collection of three properties located in the vicinity of Gympie, and a central Queensland breeding enterprise selling finished steers, run over two adjoining properties in the Arcadia Valley. These enterprises are used as case studies to assess the emissions profile and water use of the production system, from both the point of view of the enterprise on-farm emissions and an overall life cycle assessment (LCA) of enterprise outputs. Opportunities for sequestering carbon in trees are also investigated.

The total on-farm emissions modelled for the two properties are:

- 2,984 t CO2-e/yr (or 1.93 t/livestock unit) for the 634-cow enterprise turning off weaner cattle at Gympie
- 5,725 t CO2-e/yr (or 1.70 t/livestock unit) for the 720-cow enterprise turning off finished steers in the Arcadia Valley.

The on-farm emissions are largely attributable to enteric methane emissions from the beef herd, which represent approximately 90% of total on-farm emissions. The overall 'cradle-to-farm gate' GHG emissions associated with enterprise products were 3,145 t CO2-e/yr at Gympie and 7,422 t CO2-e/yr in the Arcadia Valley, with the additional emissions coming from off-farm inputs (fuel for farm vehicles and earth moving equipment, electricity, supplementary feed, agricultural chemicals, farm services) and additionally, for the Arcadia Valley enterprise, from purchased store steers.

The carbon footprint of beef products at the farm gate ranged from 15.8-23.4 kg CO2-e/ kg live weight at Gympie and 11.6-16.5 kg CO2-e/ kg live weight in the Arcadia Valley. The key factor explaining the differences between the enterprises is the proportion of total on-farm emissions that is contributed by the breeding herd (bulls and cows), 51% of on-farm emissions at Gympie and 32% at Arcadia Valley.

This difference in intensity is interesting because it flags that there will be an optimum turn-off age/weight to minimise the intensity of emissions, that is, the quantity of emissions for each kilogram of meat produced. It would be useful to explore the potential of turn-off age optimisation for a range of defined production systems, to determine by how much GHG intensity of beef production can be changed by choosing a different age of turn-off (without any other changes to the enterprise structure or efficiency).

The ability to off-set on-farm emissions through reforestation varied between the two locations, with predicted biosequestration rates of 19.3–34.7 t CO2-e/ha/yr at Gympie (rainfall 1200 mm/year) from eucalypt plantation and 1.5–9.8 t CO2-e/ha/yr in the Arcadia Valley (rainfall 600 mm/year) through reforestation from a combination of Brigalow regrowth, leucaena and environmental eucalypt plantings.

The area that would need to be reforested to off-set on-farm emissions would be 86-155 ha at Gympie (7-13% of the holding) and 629-4,108 ha in the Arcadia Valley (9-60%).

The variability of these estimates reflects the current state of knowledge regarding carbon sequestration in forest in central Queensland, a non-traditional environment for tree planting with little research on potential growth rates of trees.

If carbon sequestration could be achieved at the higher end of the rates nominated, a significant proportion of on-farm emissions could be off-set by sequestration in timber with minimal impact on beef production. However, at the lower end of the forest sequestration range, the required level of land use change would reduce the carrying capacity, and hence beef production, especially at the Arcadia Valley site.

This study highlights a number of research areas for further attention: the carbon intensity of different farming enterprises in terms of CO2-e/unit of meat produced; estimation of the potential for environmental plantings to sequester carbon; the optimal balance between tree planting and pasture production; and the co-benefits of timber in terms of livestock production and biodiversity.

Contents

1 Background

1.1 Background

Australian agriculture is facing two interrelated imperatives – water scarcity which is being exacerbated by climate change (CSIRO and BOM 2010) and the need for greenhouse gas (GHG) abatement, to mitigate global warming. 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 13% of emissions related to land clearing (Dept Climate Change 2009). 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 water for agricultural production and carbon storage.

This paper investigates the GHG emissions and water use of two beef enterprises - a south eastern Queensland breeding enterprise selling weaners, run on a collection of three properties located in the vicinity of Gympie, and a central Queensland breeding enterprise selling finished steers, run over two adjoining properties in the Arcadia Valley. These enterprises are used as case studies to assess the emissions profile and water use of the production system, from both the point of view of the enterprise on-farm emissions and an overall life cycle assessment (LCA) of enterprise outputs. Opportunities for sequestering carbon in trees are also investigated.

2 Project Objectives

2.1 Project Objectives

The objective of this project is to produce two case studies of the 'carbon footprint' of beef production in northern Australia that will:

- Provide understanding of the net on-farm greenhouse gas emissions of two example production systems;
- Assist in communication with producers and industry on net emissions and mitigation potential on farm; and
- Provide datasets of on-farm greenhouse gas emissions and sequestration potential, and some data on water use, for further analysis by MLA to inform planning for future research investment.

3 Methodology

3.1 Description of the case study production systems

3.1.1 Gympie Case Study

The weaner breeding enterprise operates across three landholdings in the Gympie district, with an approximate area of 1215 ha. Average rainfall in the region is 1124 mm per annum (Bureau of

Meteorology 2010). Detailed farm records were collected for a three year period (2007-2009), the period recommended for livestock farming systems (Eady and Ridoutt 2009). The structure of the enterprise was relatively stable over the three years and GHG emissions are based directly on the farm data provided.

The main business enterprise is a self-replacing beef herd based on a mix of breeds (Braham and Charolais) with a 50-70% Bos indicus content. The primary product from this system is weaner steers, sold for growing out and finishing on other properties before slaughter. However, the enterprise also produces significant numbers of cull cows and surplus heifers (Table 1). In 2008, the decision was made to move to selling animals as yearlings (18 months of age) rather than weaners (9 months of age). However, for the purposes of the case study it was assumed that the turn-off of animals in the 3rd year occurred at 9 months of age, and the additional inputs and land resources acquired that year to support the increase in stock numbers were not included in the analysis.

The assumptions used for the enterprise are as detailed. The breeding herd is 634 cows comprising 454 mature cows and 180 1st calf heifers. Annual replacement rate of cows is 180 per year. Cows are first mated at approximately 2 years of age. Weaning rate is 82% with 180 replacement heifers required each year and 80 surplus heifers sold. Production of weaner steers is 260 per year from the self-replacing herd. Bulls required for the herd are 22 with replacement rate of 3 per year. The overall herd size in livestock units (LSU; NSW DPI 2007) is 1,448 LSU. Cull cows are sold at 454 kg live weight for $1.72/kg, bulls sold at 688 kg for $1.79/kg, cull heifers sold at 340 kg for $1.33, surplus weaner heifers sold at 224 kg for $1.60 and weaner steers sold at 239 kg for $1.58. These prices reflect historic prices for 2007-2008 for the particular lots sold.

There are two main pasture systems - native pasture comprised largely of grasses, and improved pasture with a mix of grasses and legumes. The improved pastures are planted to achieve an initial mix of 60% legumes and 40% grasses, but the legume content declines over 4 years post-planting to stabilise at 40%. The grasses planted are Rhodes grass (Chloris gayana), Setaria (Setaria sphacelata), blue grass (Dichanthium sericium), green panic (Panicum maximum), kikuyu (Pennisetum clandestinum), paspalum (Paspalum dilatatum) and the legumes plated are Wynn cassia (Chamaecrista rotundifolia), glycine (Neonotonia wightii), siratro (Macroptilium atropurpureum) and white clover (Trifolium repens). Approximately 30 ha of pasture improvement is undertaken each year which involves burning the existing pasture, cultivating the soil and planting. No other burning is undertaken on the property and wildfires have been avoided for the last 12 years with grazing management and firebreaks. Pastures are rotationally grazed with animals spending between 1-2 days on each paddock.

In addition to GHG sources and water use, an assessment was also done of possible GHG sinks on the property. This included timber plantings but not soil carbon. On one of the land holdings there has been 60 ha of post-1990 timber plantation established, comprised of Dunn’s White Gum (Eucalyptus dunnii) for commercial timber production. Potential carbon sequestration rates for the enterprise were assumed to be similar to these plantings.

3.1.2 Arcadia Valley Case Study

The finished steer breeding enterprise operates across two adjacent landholdings in the Arcadia Valley totalling 9,908 ha. Of this area 6836 ha is useable for cattle production, the remainder being forested mountain range and escarpment. Average rainfall in the region is 628 mm per annum (Injune, Bureau of Meteorology 2010) while property records show a long term (30 years) mean of 600 mm. Farm records were available for a two year period (2008-2009 financial years). Due to major restructuring of the farm business, herd structure and subsequent cattle sales over this period were not closely representative of the long term outputs from a self-replacing breeding enterprise. In this instance, the decision was made to use key farm records to model a typical cattle enterprise on cleared Brigalow (Acacia harpophylla) country sown to Buffel grass (Cenchrus ciliaris), rather than directly represent the farm operation over those two years.

The representative business enterprise modelled is a self-replacing beef herd of a composite strain of cattle based on 35% Bos indicus breeds and 65% tropically adapted Bos taurus breeds. The primary product from this system is grass finished steers with a target live weight of 600 kg at 24-30 months of age, sold directly for slaughter. However, the enterprise also produces significant numbers of cull cows and surplus heifers, the latter being carried over to a similar age to the steers and sold directly for slaughter at approximately 500 kg live weight. In addition to home-bred cattle, 280 store steers (from a farm similar to the case study farm at Gympie) are purchased each year as weaners, and turned off at a similar weight and age to the home-bred steers. Buffel grass seed is also sold sporadically, when there is good seed set and weather allows harvesting; on average it makes up approximately 3% of farm income.

The assumptions used for the enterprise are as detailed. The breeding herd is 720 cows comprising 600 mature cows and 120 1st calf heifers. Annual replacement rate of cows is 120 per year. Cows are first mated at approximately 14 months of age. Weaning rate is 83% with 120 replacement heifers required each year and 180 surplus heifers sold for meat. Production of finished steers is 300 per year from the self-replacing herd. Bulls required for the herd are 30 with replacement rate of 5 per year. An additional 280 store steers are purchased at 240kg and finished at 600kg. The overall stocking rate for the modelled herd was 3,375 LSU which is equivalent to that of the case study property. Cull cows are sold at 500 kg live weight for $1.50/kg, bulls sold at 800 kg for $1.30/kg, finished heifers sold at 500 kg for $1.60 and finished steers sold at 600 kg for $1.70. These prices reflect historic prices for 2007-2008. For the purposes of this study it is the relativity of the prices for different classes of livestock that is important, rather than the absolute values.

The main pasture is grass-based, dominated by Buffel grass (Cenchrus ciliaris) plus smaller proportions of Rhodes grass (Chloris gayana), green panic (Panicum maximum), and blue grass (Dichanthium sericium). There is a small (2%) legume content - siratro (Macroptilium atropurpureum), Wynn cassia (Chamaecrista rotundifolia) and some medics (Medicargo spp.) Control of Brigalow sucker regrowth (typically 1 to 3 m in height) is required on approximately 50 ha per annum to maintain pasture productivity. There is no intentional burning of vegetation and although fires do occur in the grasslands of the Valley, there have been no grass fires on the case study farm for the last 30 years. Pastures are rotationally grazed with animals spending between 2-21 days on each paddock depending on the time of year and growth rates.

In addition to GHG sources and water use, an assessment was also done of possible GHG sinks on the property. This included timber plantings but not soil carbon. On one of the land holdings there are 11 ha of post-1990 tree planting mainly in laneway configurations, using Chinchilla White Gum (Eucalyptus argophloia). In the early 2000s, leucaena was established on 1200 ha, in a planting configuration of two closely spaced rows (0.3m), with 8 m spacing between the twin rows. The trees are grazed regularly and the tree height is approximately 2.5 m.

3.2 System boundary for life cycle assessment

The LCA was undertaken for the beef enterprise only, and did not include forestry activities, which are considered independently later in the paper. The system boundary for the study is illustrated in Figure 1. For the LCA, the system boundary did not include inputs from infrastructure and capital investment processes to generate energy or manufacture inputs (i.e. provision of power station or factory infrastructure) and the life cycle was completed at the farm gate.

GHG emissions associated with the production of beef cattle were classified into sectors as per the National Greenhouse Accounts for Australia (DCC 2009). These sectors are Agriculture (which includes enteric methane and nitrous oxide (N2O) emissions from livestock, N2O emissions from N-fertiliser and legume pastures, and non-CO2 GHG emissions from savanna burning), Stationery Energy (electricity generation) and Energy-Transport (liquid fuel combustion).

A system boundary diagram that covers both enterprises (Figure 1) shows the processes that contribute to each sector. On-farm (Agriculture sector) emissions, shown in green, include emissions from livestock, the use of nitrogen fertiliser, savanna burning and N2O from legume-based pastures. Grass production is included to complete the processes that provide pasture and seed but there are no direct emissions associated with the growth of grass pastures – any breakdown and release of carbon as plant material decays is assumed to be balanced by new growth that fixes carbon.

Processes shown in orange are general on-farm processes that contribute to the whole farm operation and need to be allocated to all farm products. GHG emissions associated with these inputs are covered in the Stationery Energy and Energy-Transport sectors, rather than Agriculture, so they are included in the LCA system boundary but are not included in the on-farm emissions (even though some of the liquid fuel used to produce beef is combusted on-farm).
The inputs shown in blue can be attributed to specific on-farm processes (i.e. vaccines for cattle); again the GHG emissions associated with these processes are included in the LCA but not the on-farm figures. Figure 1 also shows where transport has been explicitly modelled. As the system boundary is to the farm gate, transport post-farm gate is not included in the LCA.

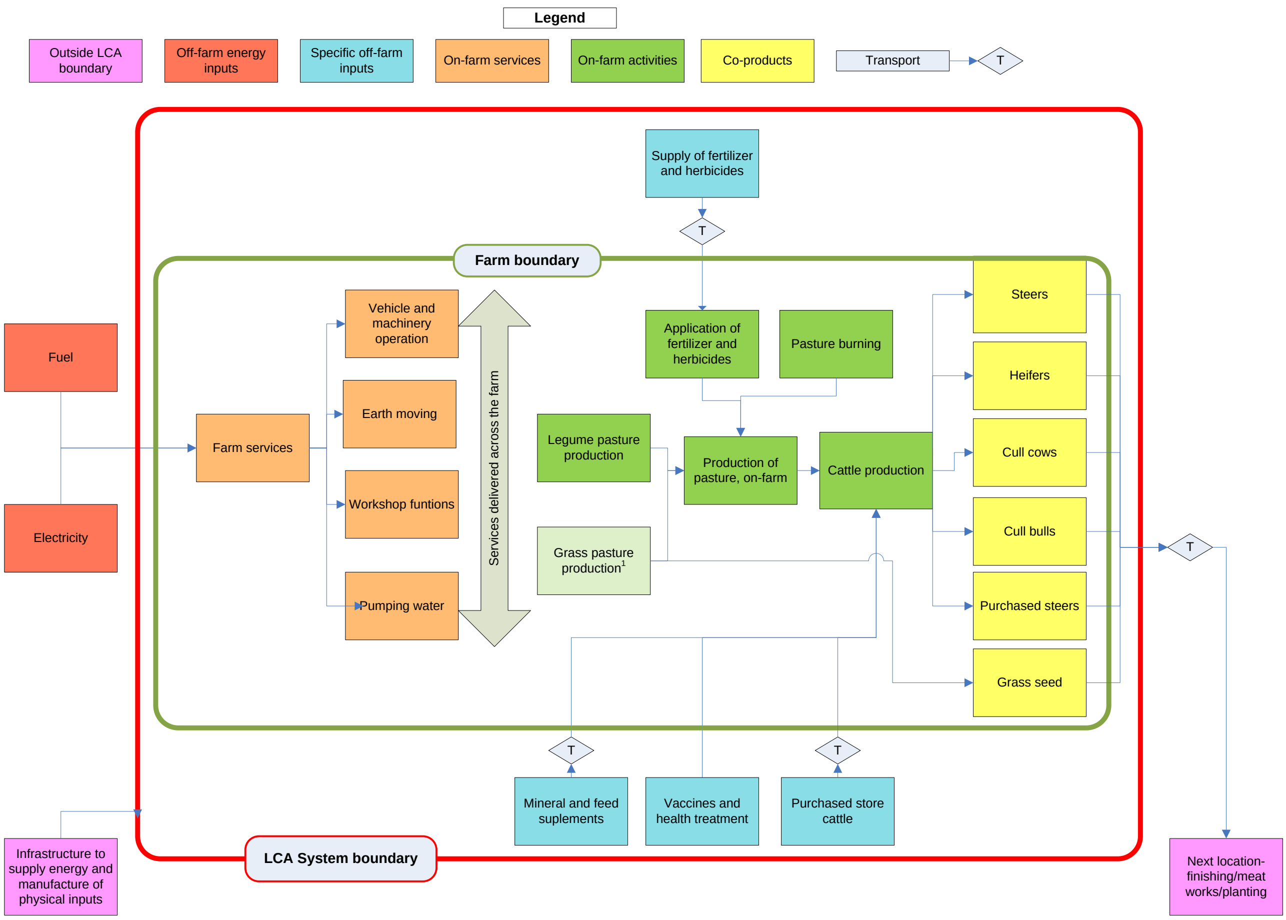

Figure 1. Farm boundary and system boundary for Life Cycle Assessment for beef cattle enterprises in Queensland
1 No direct GHG emissions are associated with grass pasture production.

3.3 Functional units and allocation

The functional units (FU) used for farm products (at the farm gate) are given in Table 1. The choice of 1 kg of live weight as the FU 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 farming enterprise, arises when there are multifunction processes, that is, the enterprise produces interrelated products. For this example, the two enterprises produce 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.

The ISO recommendation for allocation (ISO 2006) is to first avoid allocation altogether, if at all possible, by dividing the multifunction process into sub-processes or expanding the system to include functions related to all the products. In this instance, the production of the primary product – steers, cannot be separated from the production of heifers, cull cows and bulls in the self-replacing herd on each property. However in the Arcadia Valley case study, the production of steers that were purchased at a young age from another breeding property can be treated as a separate process and is modelled in this manner.

The other alternative for avoiding the need for allocation is system expansion which allocates 100% of the environmental impacts to the primary product (steers) and models the co-products (surplus heifers, cull cows and bulls) 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 cows and bulls would most likely go to the lower value processed meat sector and substitutes could be culled sheep or pigs. An LCA that uses this approach (known as a consequential modelling of LCA) needs then to model not just the cattle enterprise but also the sheep or pig enterprise. This allows the “consequence”, in terms of environmental impact, of a change in steer production to be assessed.

Amongst LCA practitioners (Finnveden et al. 2009) there is some consensus that an attributional modelling approach to LCA is appropriate when the goal 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, the attributional approach was used as the goal of the study was to benchmark the GHG emissions and water use for the two production systems. Therefore, economic allocation, based on farm income records, was used to allocate GHG emissions and water use to each co-product within the self-replacing beef herd (Table 1). Allocation based on mass is also given in Table 1 as a comparison but all the results are presented on an economic allocation basis.

Likewise, economic allocation was used for the Arcadia Valley case study to allocate overall farm inputs and services (coloured orange in Figure 1) to the three groups of products – livestock from self-replacing herd (74%), purchased steers (23.3%) and Buffel grass seed production (2.7%).

Table 1. Functional unit for beef enterprise products, level of production of products leaving the farm and allocation (based on economics and mass) of environmental effects to co-products, within each beef enterprise.

Functional Unit at farm gate	Live weight of animal (kg)	Quantity produced per year (kg live weight)	Economic allocation to class of stock (%)	Mass allocation to class of stock (%)
SE Queensland Weaner Enterprise				
1 kg live weight of weaner beef	239	62,937	46.8	41.6
1 kg live weight cull beef cow	454	49,940	30.9	33.0
1 kg live weight cull beef heifer	340	29,920	15.0	19.8
1 kg live weight weaner beef heifer	224	6,571	6.1	4.3
1 kg live weight cull beef bull	688	2,064	1.2	1.4
Central Queensland Finished Steer Enterprise				
1 kg live weight finished beef steer	600	348,000	66.6	69.3
1 kg live weight cull beef heifer	500	90,000	20.1	17.9
1 kg live weight cull beef cow	500	60,000	12.6	12.0
1 kg live weight cull beef bull	800	4,000	0.7	0.8

3.4 Inputs, reference flow and impact categories

Inputs and reference flows describe the type and quantity of inputs and outputs for the production system. Associated with each flow are environmental impacts on global warming and water use, characterised by GHG emissions (t CO2-e) and water use (L).

In the absence of broad scale fire and deforestation, on-farm GHG emissions will be largely driven by the number of stock grazed on the property and the rate of application of nitrogen fertiliser (Eckard et al. 2000). Stock numbers can vary between years for a number of reasons – pasture availability, cash flow, level of natural increase, relative markets for different classes of animals. With the two beef case studies, fertiliser use is minimal and restricted to phosphorus for pasture establishment at Gympie, with no application of nitrogen fertiliser at either location.

GHG emissions and water use for the life cycle of the farm products include impacts from on-farm processes but also encompass impacts associated with farm inputs such as manufacture of fertiliser, production of fodder bought onto the farm, fuel and electricity inputs. The contribution of farm services (e.g. servicing of motor vehicles, veterinary inputs) to the impact categories is also included.

Farm inputs are listed in Table 3 and 6. Quantities were derived from foreground data collected from written farm records. The emissions associated with each input were drawn from a variety of sources. Background data were sourced from 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. These libraries were used for raw materials, their processing into components, transport, and energy inputs.

Beef GHG calculator (Eckard 2010) and FarmGAS (Australian Farm Institute 2009) were used to estimate direct and indirect emissions from livestock, savanna burning, nitrogen fertiliser and legume pastures, as per the current carbon accounting methodology in Australia (NGGI 2006).

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, constituting consumptive water use in biomass production.

Blue water: freshwater in aquifers, lakes, wetlands, dams and storage tanks.

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. The model used for pastures at Gympie and Arcadia Valley was GRASP, a deterministic, point-based model of soil water, grass growth and animal production (McKeon et al. 1990, 2000; Littleboy and McKeon 1997). 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, temperature, radiation interception, nitrogen availability and grass basal area. Daily weather data from 1889 to 2009 was obtained from SILO climate data sets (Jeffrey et al. 2001).

There was no use of pasture irrigation on the case study farms. The subsequent allocation of water to animal production was based on the physical quantities of plant material eaten by cattle. Any remaining biomass not consumed by the cattle was assumed to provide a range of eco-system services that were not explicitly valued as an economic output of the farm. The potential positive feedback of these services into improved production was not included in the modelling.

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 drinking water for the cattle was reticulated from an on-farm storage facility to a trough. Estimates of drinking water were based on dry matter intake and, where available, metered farm records.

Service inputs 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 were assumed to be comparable to Australia and they give the most disaggregated breakdown of sectors, allowing an estimation of the impacts associated with veterinary services, communications and farm maintenance, a level of detail not available in the Australian Input-Output Tables. The assume exchange rate was $A0.90 per $US.

As each enterprise produces primarily beef cattle, all pasture and fodder inputs were allocated to this activity. This included the addition of 30 ha/year of improved pasture to the farming system at Gympie and Brigalow regrowth control on 50 ha/year in the Arcadia Valley. In addition, where supplementary feeding of a molasses/protein meal mix or a mineral supplement was provided to one class of stock e.g. 1st calf heifers, this input was also attributed to the whole enterprise of breeding.

4 Results and Discussion

4.1 Life cycle inventory analysis for global warming and water use

4.1.1 Gympie Case Study

The mean on-farm annual GHG emissions for the beef enterprise at Gympie are 2,984 t CO2-e which equates to 1.93 t/LSU. Table 2 shows the detailed contributions from enteric methane (CH4) of cattle, nitrous oxide (N2O) emissions from dung and urine, indirect N2O emissions associated with dung and urine, CH4 emissions from manure, non-CO2 emissions from savanna burning and N2O emissions from legume pasture residues. The contribution of these categories is plotted in Figure 2. Overwhelmingly GHG emission sources are directly from livestock, with a significant but smaller contribution (5.5%) from legume pastures and a minimal contribution from manure and savanna burning. The contribution of the breeding animals (bulls and cows), which could be considered as the 'overhead' emissions cost of producing sale animals, is 1,516 t CO2-e or 51% of total on-farm emissions.

Table 2. Mean GHG emissions from direct livestock emissions (enteric methane: CH4, and nitrous oxide from dung and urine: N2O), indirect emissions associated with dung and urine, CH4 emissions from manure, non-CO2 emissions from savanna burning and N2O emissions from legume pasture for Gympie property.

Emission source	Emission quantity (t CO2-e/year)	Emissions per livestock unit – LSU (t CO2-e/year)	Enterprise parameters
CH4 – Enteric	2,666	1.726	634 cow herd and followers, totally 1,497 head of mixed classes and ages, equivalent to 1,545 LSU.
N2O – Indirect	62	0.040	
N2O - Dung, Urine	86	0.056	
CH4 – Manure	1.7	0.001	Manure deposited under grazing conditions
Non-CO2 GHG gases- Savanna burning	4.9	0.003	30 ha burnt per annum
N2O – Legume pasture	163	0.106	729 ha of improved pasture with 40% legume content.
Total on-farm GHG emissions	2,984	1.931	

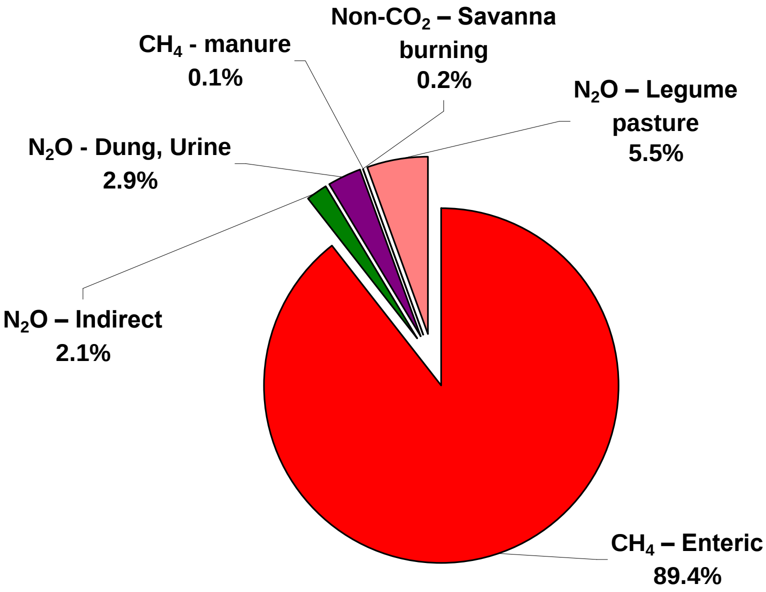

Figure 2. On-farm emissions from beef enterprise showing livestock, savanna burning, legume pasture and indirect GHG emissions for Gympie

However, the on-farm GHG emissions of 2,984 t CO2-e represent only part of the total GHG emissions associated with the production of beef. The LCA for the farm products shows that the total emissions for the 'cradle-to-farm gate' supply chain are 3,145 t CO2-e. Table 3 details of the origin of the additional 161 t of emissions.

Table 3. Off-farm GHG emissions associated with the manufacture of farm inputs, production and consumption of energy inputs, transport and farm services for Gympie property.

Inputs	Quantity/year	Quantity of GHG emissions (t CO2-e/year)	Life cycle inventory source
Electricity - non-domestic	40,019 kWh	35.9	Australian Unit Process LCI
Diesel	7,054 L	25.0	Australian Unit Process LCI
Copra meal and molasses	206 tonnes	20.7	Ecoinvent unit processes
Herbicides	1,200 kg	17.6	Ecoinvent unit processes
Farm maintenance	$A 23,338	15.1	US
Petrol	4,703 L	13.2	Australian Unit Process LCI
Bulldozer operation	82 hours	8.5	CSIRO LCI
Urea supplement for stock	8.12 tonne	7.0	Australian Unit Process LCI
Automotive repairs	$A 6,600	3.7	US Input Output
Dog food	12 dogs	3.4	CSIRO LCI
Veterinary services	$A 4,570	2.3	US Input Output
Pasture establishment	30 ha	2.1	CSIRO LCI
Silage	21 tonne	1.7	CSIRO LCI
Communications	$A 5,197	1.7	US Input Output
Transport between properties	26,000 animal.km	1.4	Australian Unit Process LCI
Cattle health treatment (vaccines and parasite control)	115 kg	1.3	Ecoinvent unit processes
Other	Minor inputs unspecified	3.7	Ecoinvent unit processes; Australian Unit Process LCI
Total off-farm GHG emissions		161	

The LCA network diagram showing the contribution of individual processes from ‘cradle-to-farm gate’ is given in Figure 3. The two primary flows of emissions, indicated by the thickest red arrows (Figure 3), are from livestock emissions allocated to the two largest income earning classes of animals – weaner steers and cull cows (Table 1).

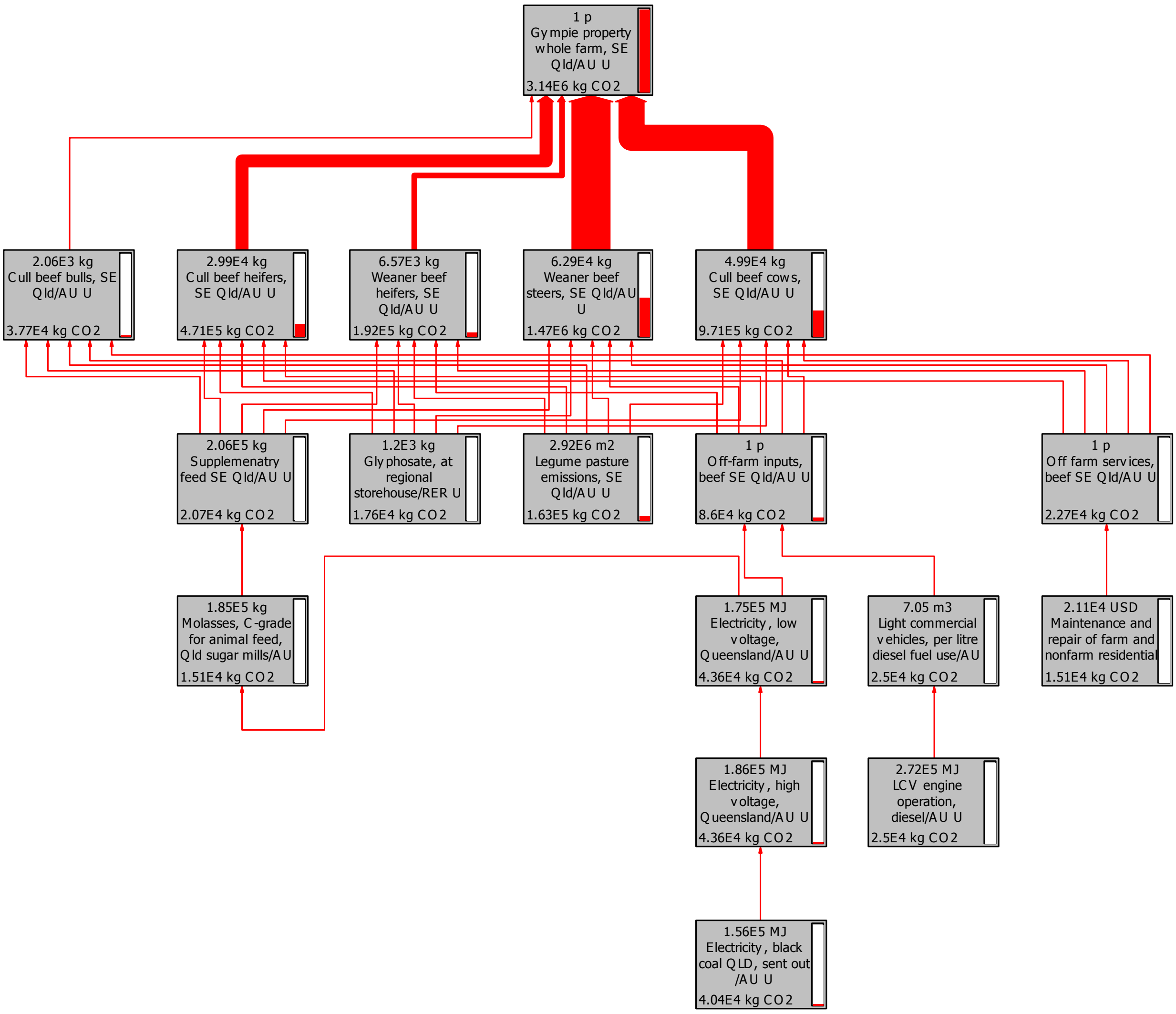

Figure 3. Network diagram for the Gympie property showing global warming potential of contributing process with cut-off for process impact set to 0.45 % of total impact, with weight of arrows reflecting magnitude of flow.

The resulting GHG intensity and water use for enterprise products can be calculated using LCA. These are presented in Table 4.

Table 4. Greenhouse gas intensity (kg CO_2-e/Function Unit of product) and water use (L/Functional Unit of product) for the range of outputs from the beef enterprise for the Gympie property using economic allocation.

Functional Unit at farm gate	GHG intensity/kg live weight (kg CO_2-e)	Water use/kg live weight (L)		
		Green water	Blue water from on-farm sources	Blue water from off-farm sources
1 kg live weight weaner beef steer	23.4	13,026	98	52
1 kg live weight cull beef cow	19.4	10,822	82	44
1 kg live weight cull beef heifer	15.8	8,768	66	35
1 kg live weight weaner beef heifer	29.2	16,233	122	65
1 kg live weight cull beef bull	18.3	10,121	77	41

4.1.2 Arcadia Valley Case Study

The mean on-farm annual GHG emissions for the beef enterprise in the Arcadia Valley are 5,735 t CO_2-e which equates to 1.70 t/LSU. Table 5 shows the detailed contributions from enteric methane (CH_4) of cattle, nitrous oxide (N_2O) emissions from dung and urine, indirect N_2O emissions associated with dung and urine, CH_4 emissions from manure and N_2O emissions from legume pasture residues. The contribution of these categories is plotted in Figure 4. Overwhelmingly, GHG emission sources are directly from livestock, with minimal contributions from legume pastures. The contribution of the breeding animals (bulls and cows) which could be considered as the 'overhead' emissions cost of producing sale animals is 1,838 t CO_2-e or 32% of total on-farm emissions.

Table 5. Mean GHG emissions from direct livestock emissions (enteric methane and nitrous oxide from dung and urine), indirect emissions associated with dung and urine, CH_4 emissions from manure and N_2O emissions from legume pasture residues for Arcadia Valley property.

Emission source	Emission quantity (t CO_2-e/year)	Emissions per livestock unit – LSU (t CO_2-e/year)	Enterprise parameters
CH_4 – Enteric	5,367	1.590	720 cows and followers plus 280 stores purchased annually, totally 2,669 head of mixed classes and ages, equivalent to 3,375 LSU.
N_2O – Indirect	133	0.039	
N_2O - Dung, Urine	202	0.060	
CH_4 – Manure	3	0.001	Manure deposited under grazing conditions
N_2O – Legume pasture	20	0.006	6,836 ha of improved pasture with 2% legume content.
Total	5,725*	1.696	

* The contribution (livestock emissions) of the 280 store steers while they are on the Arcadia Valley property is 1,167 t CO_2-e/year.

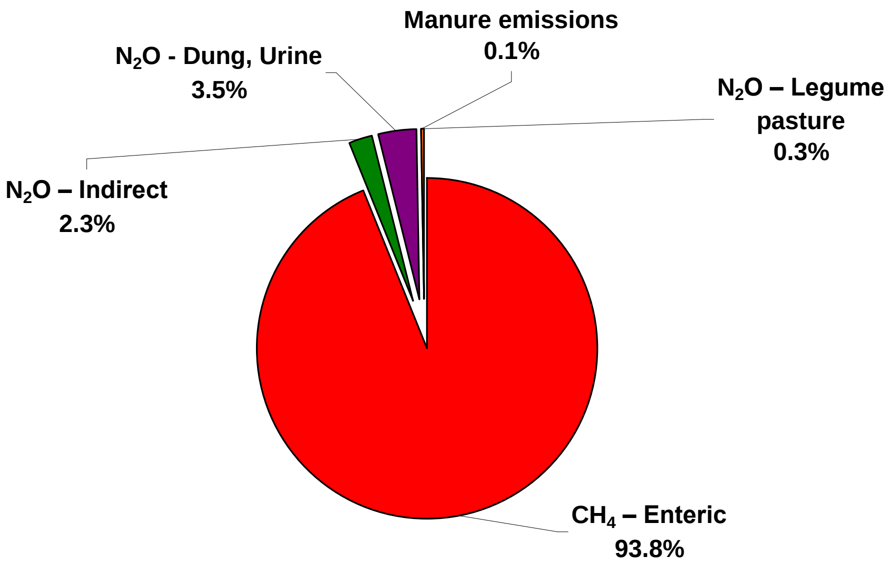

Figure 4. On-farm emissions from beef enterprise showing livestock, legume pasture and indirect GHG emissions for Arcadia Valley.

However, the on-farm GHG emissions of 5,725 t CO2-e represent only part of the total GHG emissions associated with the production of farm products. The LCA for the farm shows that the total emissions for the 'cradle-to-farm gate' supply chain is 7,352 t CO2-e. Table 6 details of the origin of the additional 1,627 t of emissions.

Table 6. Off-farm GHG emissions associated with the manufacture of farm inputs, production and consumption of energy inputs, transport and farm services for Arcadia Valley property

Inputs	Quantity/year	Quantity of GHG emissions (t CO2-e/year)	Life cycle inventory source
Purchased store steers	280 head	1,500	CSIRO LCI
Diesel	14,330 l	50.9	Australian Unit Process LCI
Electricity - non-domestic	24,553 kWh	22.1	Australian Unit Process LCI
Petrol	6,808 l	19.1	Australian Unit Process LCI
Farm maintenance	$A 20,500	13.2	US Input Output
Transport of store steers	140,000 animal.km	7.7	Australian Unit Process LCI
Bulldozer operation	50 hours	5.2	CSIRO LCI
Excavator operation	31.5 hours	3.1	CSIRO LCI
Control Brigalow suckers	50 ha	1.8	CSIRO LCI
Communications	$A 5,000	1.6	US Input Output
Buffel seed harvesting	57.2 ha	1.6	CSIRO LCI
Automotive repairs	$A 2,000	1.1	US Input Output
Cattle health treatment (largely vaccines)	5 kg	0.06	Ecoinvent unit processes
Total off-farm GHG emissions		1,627	

The LCA network diagram showing the contribution of individual processes from cradle-to-farm gate is given in Figure 5. The two largest flows of emissions, indicated by the thickest red arrows (Figure 5), are from livestock emissions allocated to the two largest income earning classes of animals – home-bred steers and purchased steers.

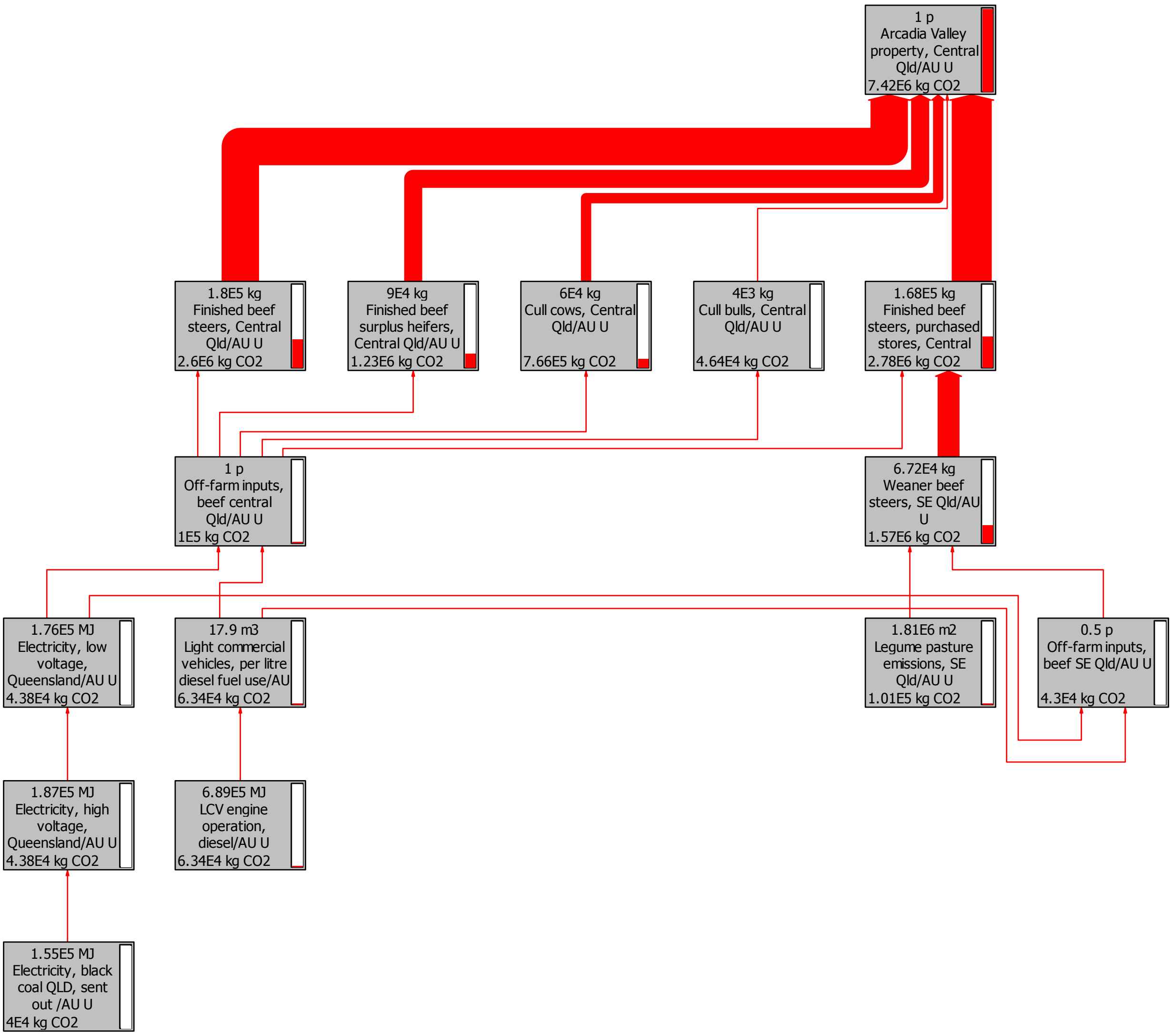

Figure 5. Network diagram for the Arcadia Valley property showing global warming potential of contributing process with cut-off for process impact set to 0.45 % of total impact, with weight of arrows reflecting magnitude of flow.

The resulting GHG intensity and water use for the beef enterprise products can be calculated using LCA. These are presented in Table 7.

Table 7. Greenhouse gas intensity (kg CO2-e/Function Unit of product) and water use (L/Functional Unit of product) for the range of outputs from the beef enterprise for the Arcadia Valley property using economic allocation

Functional Unit at farm gate	GHG intensity/kg live weight (kg CO2-e)	Water use/kg live weight (L)		
		Green water	Blue water from on-farm sources	Blue water from off-farm sources
1 kg live weight finished beef steer	14.5	9,180	64	0.1
1 kg live weight finished beef steer, purchased as store	16.5	9,600	70	21
1 kg live weight cull beef heifer	13.6	8,640	60	0.1
1 kg live weight cull beef cow	12.8	8,100	56	0.1
1 kg live weight cull beef bull	11.6	7,360	51	0.1

4.2 Comparing and contrasting case studies

The Gympie and Arcadia Valley properties represent different Queensland beef production systems, in that the Gympie operation breeds weaners which are then purchased by other enterprises for growing out to market weight, while the Arcadia Valley operation breeds and grows animals out to finishing weight. In addition, the Arcadia Valley operation buys in store cattle similar to those produced at Gympie, to make use of surplus pasture. The total on-farm GHG emissions for each case study, 2,984 t CO2-e at Gympie and 5,725 t at Arcadia Valley, reflects the number and age distribution of cattle running at each location. When expressed on a per livestock unit basis, the emissions at Gympie are 1.93 t/LSU compared to 1.70 t/LSU at Arcadia Valley.

At the farm gate the GHG emissions intensity (kg CO2-e per kg live weight turned off the property) is higher for all co-products from the weaner enterprise at Gympie than the finishing enterprise in the Arcadia Valley (15.8-23.4 versus 11.6-16.5 kg CO2-e/kg live weight). The greater legume content of pasture at Gympie (40% versus 2%) goes part of the way to explaining this difference but even if the legume content were 2% at both locations the intensity would only decrease by about 5%, for example to 22.2 kg CO2-e/kg live weight for weaner steers at Gympie.

The higher carbon footprint for the purchased steers (assumed to be produced by a similar property to the case study farm at Gympie) is a result of a combination of effects, with the transport adding only 0.05 kg CO2-e/kg live weight, while the different production system for the store steers accounts for the balance.

The key factor explaining the differences, in farm gate emissions intensity between the two enterprises, is the proportion of total on-farm emissions that is contributed by the breeding herd (bulls and mated cows), 51% of on-farm emissions at Gympie and 32% at Arcadia Valley. This is not due to differences in weaning rates as they are similar at both sites - 82% calves weaned per cow joined at Gympie and 83% in Arcadia Valley. The difference in intensity is driven by the herd structure, age of heifers at first mating and turn-off weight/age. At Gympie the ‘cost’ of the breeding herd is higher, and the emissions from the herd are spread over a relatively smaller number of kilograms of production at the farm gate, with weaners being sold at 220-230 kg live weight. At Arcadia Valley, where the animals stay on the property until 600 kg live weight, the ‘cost’ of the breeding herd is spread over a much larger mass of product. As the weaners from

Gympie move to an environment suited to finishing, and grow out to potentially a similar age/weight before slaughter, the intensity of GHG per kg of weight will reduce, although their carbon footprint will be slightly increased by the additional transport input to move them from one location to the next.

However, this difference in intensity is interesting because it flags that there will be an optimum turn-off age/weight to minimise the intensity of emissions, that is, the quantity of emissions for each kilogram of meat produced. If the weaner steers actually went to slaughter when they left the Gympie property, the carbon footprint of the resulting meat would be considerably higher than for a beast grown out to a slaughter weight of 600 kg live weight. Therefore, in terms of minimising GHG emissions for every kilogram of meat produced, it does not make sense to be eating meat from weaners compared to the heavier/older animals. Conversely there will be a maximum age, or point on the growth curve, where emissions intensity will begin to increase for meat from older animals. It would be useful to explore this turn-off age optimisation for a range of defined production systems; in addition to the growth curve for the animals the outcome will be influenced by other factors such weaning rates and age of first mating. Although useful in flagging this issue, the two case studies in this instance are not the best design for such an investigation.

In terms of absolute values for the carbon footprint of beef, the values reported here are considerably higher than those reported in other Australian beef LCA (11.6 – 18.1 kg CO2-e/kg HSCW at point of dispatch from the processor, Peters et al. 2010). Converting to a uniform functional unit of hot standard carcase weight (HSCW), a finished 600 kg live weight steer would have a HSCW of 318 kg. The carbon footprint at the farm gate for this type of animal from the Arcadia Valley property is 14.5 kg CO2-e/kg live weight, or 27.4 kg CO2-e/kg HSCW. Adding 1.4 kg CO2-e/kg HSCW for transport and meat processing (Peters et al. 2010) brings the overall carbon footprint to 28.8 kg CO2-e/kg HSCW at point of dispatch from the processor.

There may be inherent variation in production systems that give such divergent results and this will be easier to quantify as more results are published. However, there are a number of differences in assumptions between the studies that may help in explaining the large variance in carbon footprint, these being the assumed herd structure, the extent of coverage of all on-farm emissions (such as emissions from savanna burning and decomposition of legume residues) and the accounting for all emissions associated with the production of purchased cattle. Peters et al. (2010) do not include emissions from legume residues and emissions associated with store cattle before they move on to the study farm, and there is not enough detail given to compare herd structure; each of these factors can have a significant impact on the overall result. The difficulty in comparing results from different LCAs is not unique to beef; Basett-Mens and Breton (2008) report the same difficulties for milk production.

The water use to produce a kilogram of product is also higher for the Gympie property, again reflecting the overhead cost of the breeding herd in terms of water consumption. The difference in the use of off-farm blue water, approximately 50 L/kg live weight at Gympie compared to 0.1 L/kg for homebred cattle in Arcadia Valley, reflects the use of off-farm feed supplements (largely molasses) that use significant quantities of irrigation water for production.

4.3 Impact assessment for global warming and water use

Assessing the global warming impact of beef production is relatively straight forward – emissions of GHGs have a global impact regardless of their geographic location. In terms of relative impact, one 600 kg finished steer from the Arcadia Valley is equivalent to 33% of the Australian per capita global warming impact. 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.

4.4 Opportunities to mitigate or offset on-farm GHG emissions

Practical and proven on-farm approaches for mitigating emissions from ruminant livestock are currently limited. There are some nutritional approaches that give reduced CH4 emissions. These include feed supplements that may inhibit CH4 production in the rumen and the introduction of feed types that result in lower CH4 emissions (Beauchemin et al. 2008). Manipulation of the microbes in the rumen that produce CH4 can also give temporary reductions in their activity (McAllister and Newbold 2008). However, results are often variable and the effect is transitory, as the methanogen microbes adjust to the new conditions.

The most amendable technology, currently available to farmers, targets improved efficiency in the breeding herd/flock and reduced days to market for growing animals; this is encapsulated in total herd productivity (Bentley et al. 2008, Charmley et al. 2008, Hunter and Niethe 2009). However, if good farmers are already operating at close to their productive potential there is little room for significant emissions abatement unless the actual number of animals is reduced. In addition, some improvements in efficiency, for example improved reproductive rates, may not necessarily lead to less animals in the herd, as farmers are more likely to take the added income from the greater turn-off of animals than reduce the number of cows, to keep turn-off constant. However, as indicated above, it would be useful to explore the potential of turn-off age optimisation for a range of defined production systems, to determine by how much GHG intensity of beef production can be changed by choosing a different age of turn-off (without any other changes to the enterprise structure or efficiency).

Farmers are able to make decisions about the allocation of land for different uses and there is the opportunity to consider switching to activities that establish carbon sinks, such as growing trees and building soil carbon stores. There is information available on carbon stored by trees and the estimates have a certain level of predictability allowing models to be developed for estimating sequestration rates (e.g. FullCAM, Richards et al. 2005) but the scarcity of data on soil carbon trends in pastures, plus the high variability in outcomes where there is data (Gifford & McIvor 2009, Sanderman et al. 2010), makes meaningful individual enterprise estimations on soil carbon storage impossible at this point in time. Baldock and Broos (2008) predict that in farming systems that are working at close to maximum efficiency, soil carbon storage is likely to be undergoing minimal change. Due to uncertainty regarding soil carbon as a GHG sink, these case studies only explore the option of growing trees.

Sequestration rates for plantation timber in the Gympie region range from 19.3-34.7 t CO2-e/ha/year over a 13 year period (Forest Enterprises Australia Limited, unpublished data; Table 8). Extending the growth curve out to 30 years is likely to bring this estimate back to 15-25 t CO2-e/ha/year (Phil Polglase, pers comm.). The FullCAM estimate is higher, 31.8 t/CO2-e/ha/year to be sequestered over a 30 year time horizon, which may indicate that the particular case study site is in a favourable area for timber production for the region. There are existing stands of Eucalyptus dunni on the Gympie case study property which will be measured in the future and this will assist in narrowing the predicted range for potential carbon sequestration. The published data for carbon sequestration in forest is much more variable for the Arcadia Valley location. At two locations with similar rainfall to the Arcadia Valley (600 mm), sequestration rates for Eucalyptus argophloia were 4.5 and 9.8 t CO2-e/ha/yr over the first 6 years of growth (Lee et al. 2009), using measured stem volume and various expansion factors to extrapolate to carbon storage (Phil Polglase, pers comm.). The FullCAM estimate for this species is much lower, at 1.5 t CO2-e/ha/yr. The estimates from Donaghy et al. (2009) of 3.85 t CO2-

e/ha/yr for a row eucalypt configuration are in the mid-range and are based on measurements of regrowth stand basal area. The region considered by Donaghy et al. (2009) was the Fitzroy basin where rainfall exceeded 600 mm, a higher average rainfall than the Arcadia Valley (600mm). It is likely that the higher rainfall would result in greater tree growth rates for the Donaghy et al. (2009) study. The FullCAM estimate of sequestration from environmental plantings (species not specified) in the Arcadia Valley is 3.0 t CO2-e/ha/yr, which is similar to the estimate of 2.5 t CO2-e/ha/yr (Donaghy et al. 2009) for Brigalow regrowth and leucaena (Shelton & Dalzell 2007) in the Fitzroy basin. The variability of these estimates reflects the current state of knowledge regarding carbon sequestration in forest in central Queensland, a non-traditional environment for tree planting with little research on potential growth rates of trees.

Table 8. Estimates of rates of carbon sequestration for forestry options at Gympie and in the Arcadia Valley

Type of forestry	Mean sequestration rate (t CO2-e/ha/yr)	Source	Comments
Gympie			
Plantation - Eucalyptus dunnii	31.8 (over 30 years)	FullCAM modelling estimate	Model well parameterised for plantation timbers in established forestry environments.
Plantation - Eucalyptus dunnii	19.3 – 34.7 (over 13 years)	Forest Enterprises Australia Limited modelling estimate	Estimate for 13 years growth based on field measurement at 7 years of growth across a range of plantations in Gympie region.
Arcadia Valley			
Environmental planting (species not specified)	3.0 (over 30 years)	FullCAM modelling estimate	Assumed to be equivalent to regrowth of Brigalow.
Plantation - Eucalyptus argophloia	1.5 (over 30 years) 1.4 (over 6 years)	FullCAM modelling estimate	Eucalyptus argophloia as a single species planting is assumed to have slower initial growth rate compared to environmental planting when modelled in FullCAM, however long term (>100 years) sequestration potential likely to be similar.
Plantation - Eucalyptus argophloia	4.5 – 9.8	Lee et al. 2009 field measurement	Two sites with similar rainfall to Arcadia Valley but only measured over 6 year's growth.
20 m belts with 60 m separation – Eucalyptus spp.	3.9 (over 25 years)	Donaghy et al. 2009 modelling estimate	Modelled for 25 year period in Fitzroy Basin where rainfall >600mm and based on tree stand basal area increase for eucalypt regrowth.
20 m belts with 60 m separation – Acacia harpophylla	2.5 (over 25 years)	Donaghy et al. 2009 modelling estimate	Modelled for 25 year period in Fitzroy Basin where rainfall >600mm and based on tree stand basal area increase for Brigalow regrowth.
Leucaena stands in row configuration	2.9 (over 5 years)	Shelton & Dazell (2007)	Accumulation after 5 years in above and below ground biomass assumed to be minimal as stock then graze the trees to a constant height.

Based on the figures in Table 8, the ability to off-set on-farm emissions through reforestation varied between the two locations, with predicted biosequestration rates of 19.3 – 34.7 t CO2-

e/ha/yr at Gympie from eucalypt plantation and 1.5 – 9.8 t CO_2-e/ha/yr in the Arcadia Valley through reforestation from a combination of Brigalow regrowth, leucaena and environmental eucalypt plantings. Each case study site had existing pre-1990 native forest stands, many of which could be considered to be in equilibrium for carbon storage, but those that may still be accumulating carbon would not be eligible as a carbon-offset under the national GHG accounting framework. Excluding this area, the area that would need to be reforested to off-set on-farm emissions would be 86-155 ha at Gympie (7-13% of the holding) and 629-4,108 ha in the Arcadia Valley (9-60%). If carbon sequestration could be achieved at the higher end of the rates nominated, a significant proportion of on-farm emissions could be off-set by sequestration in timber with minimal impact on beef production. However, at the lower end of the sequestration range, the required level of land use change would reduce the carrying capacity, and hence beef production, especially at the Arcadia Valley site.

5 Success in Achieving Objectives

5.1 Success in Achieving Objectives

This report covers all the objectives for the project:
- it provides two case studies for GHG emission for beef production in Queensland, including life cycle inventory on water use
- it provides all the primary data used for the study and life cycle assessment
- it provides that data in a format that can be used in MLA Fact sheets for use as industry publications and at field days.

6 Impact on Meat and Livestock Industry – now & in five years time

6.1 Impact on Meat and Livestock Industry – now & in five years time

The GHG case studies give beef producers a benchmark for the level of emissions likely to be associated with their enterprises and the possible sequestration potential from forest vegetation. The current policy domain for GHG mitigation in Australia is evolving, with current activities within the Department of Climate Change and Energy Efficiency focused on the design of offsets to incentivise mitigation of GHG emissions in agriculture. Results from these case studies will inform beef producers as to the potential for participation in the carbon offset market, in as much as the case studies provide a benchmark for current systems of production, thus enabling the effectiveness of different scenarios to be quantified.

The case studies can be used to raise the level of awareness and engagement in climate change and carbon markets.

In five years time, it is likely that there will be established carbon markets and this type of benchmarking of systems will be underpinning the design of offsets being traded in the market.

7 Conclusions and Recommendations

7.1 Conclusions and Recommendations

The total on-farm GHG emissions modelled for the two properties are:
- 2,984 t CO_2-e/yr (or 1.93 t/livestock unit) for the 634-cow enterprise turning off weaner cattle at Gympie
- 5,725 t CO_2-e/yr (or 1.70 t/livestock unit) for the 720-cow enterprise turning off finished steers in the Arcadia Valley.

The on-farm emissions are largely attributable to enteric methane emissions from the beef herd, which represent approximately 90% of total on-farm emissions. The overall ‘cradle-to-farm gate’ GHG emissions associated with enterprise products were 3,145 t CO2-e/yr at Gympie and 7,422 t CO2-e/yr in the Arcadia Valley, with the additional emissions coming from off-farm inputs (fuel for farm vehicles and earth moving equipment, electricity, supplementary feed, agricultural chemicals, farm services) and additionally, for the Arcadia Valley enterprise, from purchased store steers.

The carbon footprint of beef products at the farm gate ranged from 15.8-23.4 kg CO2-e/ kg live weight at Gympie and 11.6-16.5 kg CO2-e/ kg live weight in the Arcadia Valley. The key factor explaining the differences between the enterprises is the proportion of total on-farm emissions that is contributed by the breeding herd (bulls and cows), 51% of on-farm emissions at Gympie and 32% at Arcadia Valley.

The ability to off-set on-farm emissions through reforestation varied between the two locations, with predicted biosequestration rates of 19.3–34.7 t CO2-e/ha/yr at Gympie (rainfall 1200 mm/year) from eucalypt plantation and 1.5–9.8 t CO2-e/ha/yr in the Arcadia Valley (rainfall 600 mm/year) through reforestation from a combination of Brigalow regrowth, leucaena and environmental eucalypt plantings.

The area that would need to be reforested to off-set on-farm emissions would be 86-155 ha at Gympie (7-13% of the holding) and 629-4,108 ha in the Arcadia Valley (9-60%).

This study highlights a number of research areas for further attention: the carbon intensity of different farming enterprises in terms of CO2-e/unit of meat produced; estimation of the potential for environmental plantings to sequester carbon; the optimal balance between tree planting and pasture production; and the co-benefits of timber in terms of livestock production and biodiversity.

8 Acknowledgements

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10 Appendices

10.1 Appendix 1

Draft paper for publication attached as separate document.