final report

Project code: B.CCH.2032

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Date published: November 2013

ISBN: 9781741919035

PUBLISHED BY

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Resource use and Greenhouse Gas emissions from the Australian beef industry: An analysis of trends from 1981-2010

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Executive summary

Australia's beef industry has changed dramatically since its beginnings 225 years ago, with significant developments continuing to the present time. This study analysed changes over the past three decades and found that three factors could be highlighted as contributing to recent productivity growth: (1) An increase in the size and production of the breeding herd; (2) A trend towards heavier slaughter cattle and faster growth rates; and (3) Growth in grain finishing from a minor component of beef production in the 1980's to the current situation where approximately 45% of young slaughter cattle are grain finished. Grain feeding in Australia, in contrast to that in many OECD countries, contributes a relatively minor proportion of total beef production with the majority remaining the product of grass feeding in extensive rangeland systems. In addition, Australia's beef herd makes up approximately 85% of total cattle and 88-92% of beef production, with the dairy herd representing a minor contribution of beef production.

There is anecdotal and individual supply chain evidence that the growth in the beef industry over recent decades has been accompanied by changes in resource use efficiency. This study was initiated by the industry to provide a more comprehensive robust analysis of the trend in environmental impacts of Australian beef production than available to date. The study aimed to quantify the trend in greenhouse gas (GHG) emissions, water use and energy use intensity (i.e. impacts per kilogram of beef produced) over the 30 years from 1981-2010[1] for the Australian beef industry by applying a life cycle assessment approach with a 'cradle-to-farm gate' boundary. The specified functional unit was 'one kilogram of live weight beef ready for processing in Australia'.

In the analysis period, changes have reflected initiatives in response to market and economic drivers and adjustments to meet environmental stewardship objectives. Changes have also occurred as a result of government legislation which over this period has restricted access to irrigation water in the major production regions of southern Australia and banned broadscale land clearing for agriculture in northern Australia. These government policies have helped to drive resource use efficiency. For example, while the use of grain has increased, reliance on other forms of high intensity production, such as irrigated pastures, has declined markedly. Overall, this study found that industry productivity drivers, together with legislated restrictions have resulted in a trend towards lower environmental impacts and more efficient resource use across the indicators studied.

GHG intensity of animal production: Over the 3 decades since 1981 there has been a decrease in GHG intensity (excluding LUC emissions) of 14%, from 15.3 to 13.1 kg CO_2-e / kg LW. The emissions profile was dominated by enteric methane (85-87%), with smaller amounts of nitrous oxide and carbon dioxide from fossil fuel use, which was consistent with previous Australian case study LCA results by the authors and others. The reduction in GHG intensity was largely the result of heavier slaughter weights across the herd, and from improved growth rates in young cattle. Grain finishing was a major contributor to improved growth rates and slaughter weights, though improvements were also seen in the grass finished

[1] Production and herd data were from financial years 1981/82 to 2010/11, whereas land use change data were for calendar years 1981 to 2010, reflecting data collection/survey periods.

herd. Most of this improvement came in the period from 1981-2001 with little change over the past decade. Poor seasonal conditions in the most recent 10 years of the analysis has resulted in poorer feed quality in many beef production regions, with the subsequent limitations to herd productivity. Analysis of total national herd turnover showed that there has been no significant improvement in weaning rate (a key herd productivity measure) over the past 30 years. However, there has been a trend towards lower mortality rates, possibly as a result of the uptake of *Bos indicus* genetics in the northern regions combined with improved herd management. This has led to a small improvement in productivity from the breeding herd because of the higher turnoff of cull breeding cows. Improvement in reproductive performance is a major goal of the beef industry from the perspective of productivity, and this also has value for its contribution to GHG mitigation. Future opportunities to reduce GHG emissions may arise from multiple directions. The Australian beef industry together with the Australian Government have invested heavily in research to mitigate enteric methane by using novel forage species, manipulating rumen function and through genetic selection. The trends identified in the present study relate primarily to animal productivity improvements, and to a lesser extent from the improved diet while cattle are finished on grain. Productivity improvement offers opportunity for further mitigation of GHG across the herd. This may be achieved via improved weaning rates, higher growth rates in young cattle and heavier turnoff weights. Higher carcase weight specifications in the Australian domestic market is one trend that can lead to improved herd productivity, provided growth rates in young cattle can be maintained. However, improved productivity relies on better nutrition, which will require further intensification of the industry to supply higher quality pastures, supplements and grain. This is a challenging target considering the prospects for greater variability in rainfall and reduced availability of irrigation water for pasture production, particularly in the south of the country. The marginal cost benefit for beef enterprises is a further consideration.

Consumptive Water use: Consumptive water use for beef production dropped to almost a third over the three decades from 1981, from 1465 L/ kg LW to 515 L / kg LW. Total consumptive water use was dominated by drinking water requirements, water supply losses and irrigation water use. The two factors accounted for the dramatic reduction in water use; a reduction in drinking water supply losses, and reductions in irrigation water use for pasture production. Over the time period analysed, a major government and landholder initiative to cap free flowing artesian bores in the rangelands resulted in a major decrease in evaporative losses and marked improvement in water use efficiency. In the same period, there was an increase in the competitive demand for irrigation water, resulting in a transfer of irrigation water away from pasture for cattle grazing to higher value industries. Reductions in irrigation for pasture were offset to a small extent by greater irrigation water use associated with grain production used for cattle feeding. Further reductions in consumptive water use in the beef industry are likely to arise from further reductions in irrigation water availability for pasture production in the major irrigation regions of southern Australia. However, this may be countered by a greater need for water storage on farms in response to climate variability, potentially resulting in higher evaporation losses.

Fossil fuel energy demand: Energy demand increased by almost two-fold over the analysis period from 6.3-11 MJ/kg LW, as a result of intensification in the supply chain. This was a clear example of trade-offs between impacts and resource use; improved productivity was partly achieved via greater inputs of energy resources to produce grain and provide higher digestibility diets. Reducing energy demand in the future will require a focus on efficiency throughout the supply chain, to compensate for further increases in inputs of feed and fertiliser which may be required to maintain and improve productivity. This is particularly relevant considering the risks of climate variability and the possibility of further reductions in irrigation water available for pastures.

Land use: While higher uncertainty in the inventory dataset for land use precluded a comparable assessment as for other resources, an inventory of land occupation for beef production using the best available information provided an indicative trend analysis. This indicated a decline in land occupation for grazing per unit of production of around 19% over the analysis period. This intensification of land use (i.e. an increase in the beef production per ha of land occupation) reflected both the increase in herd efficiency and a decrease in total land use for grazing. The grazing land loss was a result of more land under cultivation and an increase in the national protected area. Land occupation for grain production used to feed cattle increased more than 7 fold from 1981 to 2011, albeit from a low base. This growth largely reflected the growth in grain finishing, with the greatest expansion occurring in the grain growing regions from southern Queensland through New South Wales into Victoria.

Land use change GHG emissions: GHG emissions associated with direct LUC (also referred to as land transformation) for grazing were estimated to have declined by approximately 42% since 1980. There is a lower degree of confidence associated with this estimate. One source of uncertainty is the attribution of LUC emissions to beef production, where land cleared for extensive grazing moved between sheep and cattle in response to economic and environmental drivers. However, the sharp decline in emissions reflects the ban on broadscale clearing since 2006 in Queensland and in this state which dominates national LUC emissions over the analysis period grazing of beef cattle has been the major driver of clearing. It is likely that LUC GHG emissions will continue at a low level into the future. The size and (in some regions, the direction) of change will depend on policy as well as industry drivers. While it is very unlikely there will be a return to high levels of clearing for agriculture, management of woody regrowth and thickening in the grazed savannahs of northern Australia and some harvest for drought feeding will result in low ongoing emissions. Land use change may provide mitigation options for producers via strategic tree planting on less productive lands to sequester carbon, partially offsetting livestock emissions. The impacts of cultivation and other land management practices on soil carbon stocks is an area of active research in Australia. However, while remaining a minor contribution relative to animal production sources, emissions of carbon dioxide to the atmosphere due to increased soil cultivation for grain feeding were estimated to have increased from 0.1 to 0.5 kg CO_2-e / kg LW over the analysis period.

The results of this study cannot be directly compared to those for other national studies on environmental impacts and trends in beef production due to the differences in impact categories, scope and national production, geographical, vegetation and climatic characteristics. However, the results of analysis of GHG emissions are broadly consistent with the trends towards lower emissions intensity and improvements in production efficiency reported for the USA and Canada. Although again not directly comparable, the trend in greenhouse gas emissions intensity for beef cattle production and for land clearing in this study is also broadly consistent with a calculation using national inventory reporting results. In the 20 years from 1990 the Tier 2 inventory data for beef cattle (i.e. enteric methane and manure management emissions) showed a 6.5% decrease in carbon dioxide equivalent emissions per kg of total beef produced nationally. In the present study using more detailed and disaggregated data and additional sources consistent with a life cycle approach showed a GHG intensity decline of 14%.

This study identified significant gains in resource use efficiency and global warming intensity of Australian beef production over the past three decades. It also highlights that there has been some slowing of the rate of improvement since 2000 despite the potential for further productivity and environmental improvements in key areas. Realising this potential for environmental benefits aligned to ongoing growth in productivity will require a continuation of the industry commitment to R, D&E in cooperation with other stakeholders in government and non-government sectors. Ongoing monitoring based on improving data availability and quality and scientifically robust methods is also needed not only to document trends but to further understand the trade-offs between environmental criteria and production goals so that informed decisions can be made.

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LIST OF ABBREVIATIONS

ABARES – Australian Bureau of Agricultural and Resource Economics and Sciences

ABS – Australian Bureau of Statistics

ADG – Average Daily Gain

CH_4 – Methane

CO_2 – Carbon Dioxide

DCCEE – Australian Department of Climate Change and Energy Efficiency

dLUC – Direct Land Use Change

GHG – Greenhouse Gas

GWP – Global Warming Potential

IPCC – Intergovernmental Panel on Climate Change

LCA – Life Cycle Assessment

LCI – Life Cycle Inventory

LPG – Liquid Petroleum Gas

MLA – Meat & Livestock Australia

N_2O – Nitrous Oxide

NGGI – National Greenhouse Gas Inventory

O_3 – Ozone

VW – Virtual Water

WF – Water Footprint

1 Introduction

1.1 Background

All food production has an effect on the natural environment. There is an increasing focus in both political and public agendas on ensuring that agriculture, along with other industries, is responsible for minimising long-term damage to natural resources for both resource conservation and sustainability goals. Over the past two to three decades there has been a growing acceptance of the threat of anthropogenic climate change and a focus on reducing greenhouse gas emissions from human activities, including agriculture. Both concerns for resource use efficiency, conservation and climate change mitigation bring a need for information and understanding and quantification of the impacts of food production on the environment.

Agricultural practices are changing and while there is a rather romantic perception amongst some in the community that 'older' farming practices are inherently more environmentally friendly than modern, more intensive agricultural practices, a range of survey and research data is showing that there is, in reality, an increasing effort by farmers to minimise environmental impacts and to make more efficient use of limited resources such as water, land and nutrients. Sustainable intensification and increased resource use efficiency are recognised as being critical for production of adequate high-quality food for the growing and increasingly more affluent domestic and global population. Beef is an important food product, globally contributing approximately 30% of meat consumed in developed countries and a growing contribution in developing countries. The beef industry in Australia is making a responsible contribution to the 'sustainability' trend (http://www.mla.com.au/Livestock-production/Environmental-management). However, quantifying a change in multiple environmental indicators is complex, costly and very time-consuming.

Greenhouse gas emissions are now the most intensively studied environmental effect for goods and services, including agricultural products. The beef industry requires scientifically robust information to enable it to contribute to greenhouse gas mitigation while increasing production of a safe and nutritious food supply and supporting the economic viability of producers and environmental sustainability of the industry. It also needs this information and quantified assessment of other priority environmental impacts, e.g. water use, to be able to communicate its achievements to government and to consumers who are increasingly interested in understanding the environmental impact of food choices.

The introduction of climate change policies in Australia, including the Carbon Farming Initiative, adds greater urgency to the need to identify systems and practices that reduce greenhouse gas emissions while also making efficient use of other natural resources and maximising growth in productivity for a profitable industry. It is therefore timely to assemble the necessary data on industry practices and to develop methodologies for assessing greenhouse gas emissions on-farm and quantifying change over time.

Meat and Livestock Australia Ltd (MLA) have commissioned several projects investigating environmental issues, using Life Cycle Assessment (LCA) and other research approaches. The objective of this ongoing program of research has been to provide the red meat industry with the capacity to quantify and improve environmental performance and to underpin industry documentation and communication to both supporters and critics with credible and defensible data and analysis. The industry also realises that in the future, both domestic and international customers may demand information on the environmental credentials of Australian beef, and it is the responsibility of the industry to provide this information if it is to maintain and grow market share.

While a considerable amount of research is undertaken on this topic both internationally and in Australia, most projects focus on one or two environmental factors. The few projects that have aimed to undertake an integrated assessment of a number of environmental impact categories at the same time covering the whole supply chain have tended to rely on broad national survey information. For a complex, dynamic system such as a beef supply chain, it can be difficult to understand how changes in one practice may influence others, i.e. where trade-offs occur, and this is particularly relevant for research areas that bridge multiple research disciplines. LCA is a useful tool for drawing these research areas together, quantifying impacts, identifying areas of potential improvement, and providing results in the context of a relevant functional unit such as tonnes of live weight or kilogram of beef produced.

A single environmental impact category assessment using broad national data on greenhouse gas (GHG) emissions from Australia's beef cattle herd (DCCEE 2010b) and total beef production data (MLA www.mla.com.au pers. comm.) indicated a 6.5% reduction in the GHG intensity of beef (CO_2-e per kg carcase weight, CW) from 1990 to 2008. This calculation is likely to give an underestimate of the trend as it doesn't fully account for production efficiency gains due to genetics, feed quality, herd management practices and technological developments over that period. Calculations for the US showed that beef production in 2007 had a GHG intensity 16.3% lower than in 1977. Moreover, US production of beef in 2007 required only 69.9% of the animals, 81.4% of the feedstuffs, 87.9% of the water and 67.0% of the land as 30 years previously. These results for the US cannot simply be extrapolated to other countries. For example, one of the major drivers of the decline in GHG intensity of beef production in the US was the increase in contribution of slaughter animals from the dairy herd. This gain has not been mirrored in Australian beef production.

The red meat industry in Australia is interested in understanding how changes in management practices over the past 20 to 30 years have affected its environmental impact and for obtaining more accurate estimates of the trends in greenhouse gas intensity of beef production to inform goals of greater efficiency and sustainability and to support communication to stakeholders.

Additionally, it is speculated that reductions in water use have occurred over the same period, mainly due to the capping of artesian water sources and competition for irrigation water from higher profit agricultural industries leading to less irrigated pasture for beef production. Two additional resource issues, energy and land use, are also important considerations for documenting a trend in environmental impact in response to increased production intensity. In the case of land use, analysis may provide a defence against misleading reporting of high land use without qualification of the suitability of that land for alternative uses or the impact of low stocking rates on ecosystem services or landscape functionality.

1.2 Project objectives and scope

The overarching objective of the project is to quantitatively assess change in the greenhouse gas intensity of beef production in Australia through the application of credible modelling using disaggregated industry and environmental data.

The specific objectives were:

- To quantify the change over time in GHG intensity in the Australian beef herd in response to improvements in production efficiency, from the period 1981-2011.
- To quantify the change over time in water use for the Australian beef herd from the period 1981-2011.
- To quantify the change over time in energy use for the Australian beef herd from the period 1981-2011.
- To quantify the change over time in land use for the Australian beef herd from the period 1981-2011[2].

The project also aimed to identify areas of uncertainty associated with each area of environmental impact and identify knowledge gaps and future research needs in these areas.

The study applied a life cycle assessment (LCA) approach to the analysis of GHG, water use and energy use. Global warming, i.e. greenhouse gas emissions in units of carbon dioxide equivalents (CO_2-e), is the impact category of principal interest in this project, with water use, energy use and land use also assessed to provide an indication of the direction and quantum of change in these factors of environmental importance for Australian beef production. Evaluation of the trend in impact for multiple factors provides the industry with information on the potential for trade-offs in targeting environmental improvement.

This study focuses on 1981 – 2011. For beef production in Australia, this 30 year period has the best data on animal numbers and movements and the most reliable production statistics. These years also cover a period of significant change in beef production systems in Australia. Major advances included improvements in genetic selection and rapid expansion of lot feeding from the early 1990s. These changes have affected both the productivity of the industry and its environmental impacts.

1.3 Australian beef industry characteristics

1.3.1 History of grazing in Australia

While this study focuses on changes over the last 30 years of beef production, it is important to understand that the industry has evolved over time since European settlement and is constantly changing to this day. The type of animal being processed today bears little resemblance to the one slaughtered 30 years ago and indeed even earlier than that. From its meagre beginnings of a bull, bull calf and 4 cows (all Africander) in 1788, the Australian beef herd has evolved to be a complex matrix of breeds and genotypes totalling around 23 million head (excluding dairy cattle) and bred to suit a broad spectrum of markets and climatic conditions. The development is ongoing and is moulded by contemporary and looming challenges such as a global demand, changes in dietary attitudes, animal well being and climate change. At the time of first settlement when the pastoral expansion was confined to the southern and eastern regions of the continent and prior to the introduction of cattle tick, the breeding goals focussed

[2] Production and herd data were from financial years 1981/82 to 2010/11, whereas land use change data were for calendar years 1981 to 2010, reflecting data collection/survey periods.

on developing *Bos taurus* lines which suited the southern temperate zones. The main purpose for a local beef industry was to supply meat for domestic consumption driven primarily by the penal colony, early settlers and the gold rushes.

Expansion of the pastoral industry was relatively slow over the first 50 years and was restricted to the major regions of settlement and activity in NSW, Victoria, Western Australia and South Australia (Figure 1). However with the cessation of transportation of convicts in the mid eighteen hundreds and expeditions by the early explorers such as Sturt, Mitchell, Stuart, Leichardt, Forest and Kennedy (to name a few) pastoralism exploded in the next 40 years, and by 1890 most of the grazing lands in Australia had been opened up.

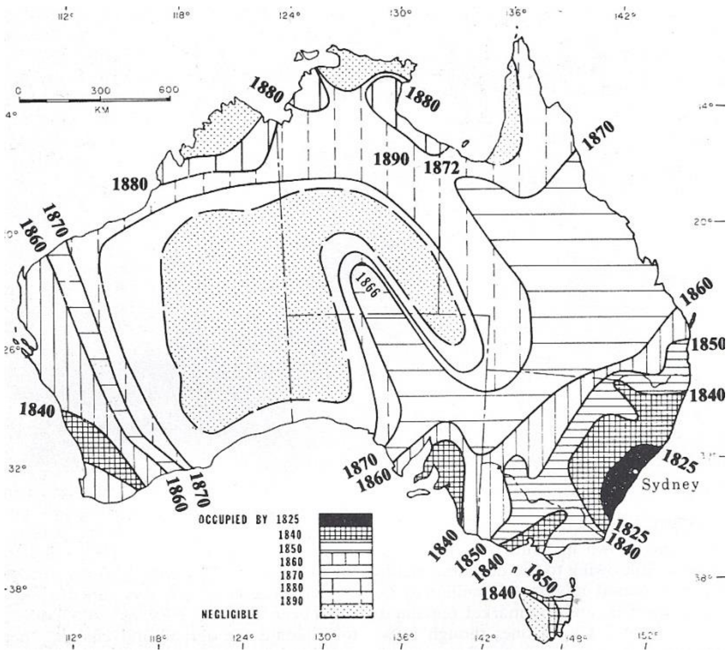


Figure 1 - Expansion of pastoralism in Australia during the nineteenth century

In the year book, Australian Agriculture (NFF 1985), the development of the beef and sheep industries are comprehensively explored. It appears that in 1862, both New South Wales and Victoria were grazing about 6 million sheep each, with Queensland only a little behind. However, by 1891, there were 62 million sheep in New South Wales, 20 million in Queensland and 13 million in Victoria. Between 1860 and 1894 the whole sheep population had risen from 20 million to 100 million, and the cattle from 4 million to more than 12 million. The great drought from 1895 to 1902 reduced the sheep population by half and much of the western districts of NSW was virtually destocked. In 1901 with the federation of the states and the emergence of a new nation, interstate tariff barriers were removed, legislation was passed enabling closer settlement and pastoralism again was growing.

Sheep numbers accelerated as wool production was much more amenable to a thriving grazing industry as processing plants, refrigeration, good roads and reliance on domestic consumption were not a prerequisite for marketing and survival. Evidence of a past flourishing wool industry can still be seen as far north as the Gulf country in Queensland and Derby in Western Australia. The national flock grew to a peak of 180 million head in 1970 but declining global demand, rising costs of labour, deteriorating land condition and increasing predation have seen a marked decline in both sheep numbers which today stand at 67 million head (Figure 2).

Photograph 1 - Over 100 Years of wool production in the Kalgoorlie region of Western Australia

Photograph 2 - Old Wool Shed Derby

Photographs 1 and 2 show images of wool production, which was an important industry in Australia's early pastoralism and which was responsible for opening up much of the rangelands.

The metamorphosis that has occurred in the beef industry has been equally as interesting. As refrigeration and shipping improved, export markets were developed and stock routes sprung up through the north creating corridors through which the beef industry could effectively operate. Beef production was gradually replacing wool in those regions less suited to sheep and the national herd grew slowly to around 16 million head by 1960.

1.3.2 Markets

By 1960, vast breeder operations were established in the dry tropical zones and these supplied store steers into the fattening regions of the channel country which were opportunistically located closer to processing facilities on the eastern seaboard. Production of older and heavier bullocks around 4-5 years of age was the main focus of this export trade along with cull cows whenever surpluses occurred. Great Britain was the main importer of the beef produced up until its entry into the European Common Market in the mid nineteen fifties. This necessitated the development of new markets into the United States and Japan. These new markets created demand and stimulated a rapid expansion in cattle numbers between 1960 and the infamous 1974 beef slump when the national herd had reached its peak of 33 million head (Figure 2). Fortuitously, the slump occurred as the construction of a network of beef roads linked into the major highways systems. At the same time, the stock routes were disappearing from the landscape and days of droving cattle were slowly coming to an end.

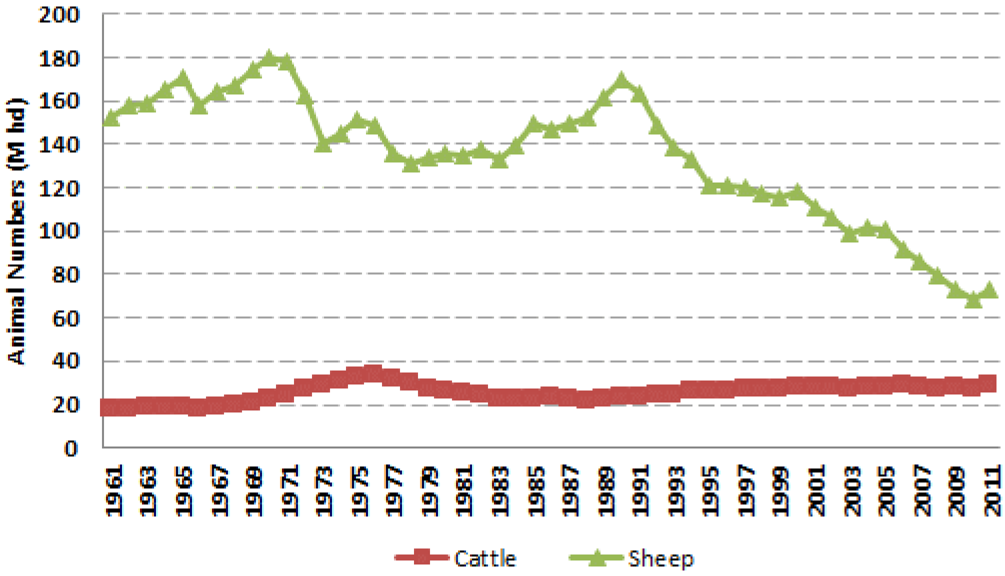


Figure 2 – Sheep and cattle numbers from 1960 to 2010 (ABS www.abs.gov.au. Accessed May 2013).

Concurrently, Australia was committed to a national eradication program for Tuberculosis and Brucellosis, and this complicated the movement of store cattle between infected and clean areas. Inland export abattoirs fortunately managed to provide an outlet for manufacturing beef during these difficult times but suffice to say, these processing plants which were located at such places as Alice Springs, Tennant Creek, Katherine, Wyndham, Broome, Darwin, Mt. Isa and Pentland have all closed. Though the Brucellosis and Tuberculosis Eradication Campaign (BTEC) imposed economic hardship on many northern beef producers it promoted new management techniques, developed new infrastructures and enabled a complete change of genotype to a more productive and tropically adapted Brahman animal. While the predominantly shorthorn breeder herd ensures good fertility, *Bos taurus* struggle in the harsher tick infested regions of the north and both growth rates and survival rates are severely impacted. The eradication of both TB and Brucellosis along with the change in genotype meant that northern Australia produced a product that was highly suited to the live export trade in south east Asia. Feedlots in

Indonesia now require a well grown *Bos indicus* type steer or heifer less than 350kgs. However, the growth in the live export trade and the move to mega sized processing facilities that can process thousands of head per day, saw the closure of the remaining export abattoirs in all but the eastern seaboard. Since June 2010, the demise of smaller export plants in inland Australia has posed enormous challenges for the northern beef industry as it seeks outlets for cull cows and steers that weigh more than 350 kg due to the live weight restriction in the Indonesian live export trade.

Meanwhile in southern states, beef producers were not quite as severely impacted by the beef slump of 1974. The drop in prices led to dramatic increases in domestic beef consumption which peaked at 68.6kg (carcase weight equivalent) per capita in 1977. Consumption dropped to 45 kg per head by 1980 and was down to 39 kg/head in 1985 (NFF 1986). The per capita consumption has hovered in the mid 30's range over the past decade. The feedlot industry was just at an embryonic stage of development in 1974 and remained dormant until after the resurgence of the beef industry in the eighties. The initial goal for lot feeding cattle was primarily targeted at the long fed export markets but this trend has changed markedly with an increased demand by local consumers for higher eating quality beef. The major supermarkets all ensure the meat that they sell has been derived from stock that have had a minimum of 60 days on grain and are less than 260 kg dressed weight at slaughter. The introduction of the Meat Standards Australia (MSA) grading system helps maintain a very high standard of product going into the domestic market. *Bos taurus* have remained dominant in the temperate regions of Australia with the Angus breed managing to capture an increasing proportion of the market. European breeds have also risen to prominence in a competitive industry that is seeking to improve growth rates and carcase traits that appeal to the palate of the demanding and discerning consumer.

1.3.3 Productivity

The following provides a summary of the characteristics of Australian beef production in 2010 (ABARES 2011a, ABS 2010a, b, MLA 2011) (Figure 3; Table 1):

- There are 59,115 properties with cattle
- Australia's national cattle herd has 26.6 million cattle and calves
- Australia's national cattle herd has 12.9 million beef cows and heifers
- The beef industry accounts for 49% of all farms with agricultural activity
- The total area operated by farms with beef cattle is approximately 332 million ha (46% of Australia's land area and 75% of all agricultural area)
- 2.5 million grainfed cattle were marketed in 2010-11 (34% of all adult cattle slaughtered)
- Australia produced 2.1 million tonnes of beef and veal in 2009
- The beef industry employs 73,524 workers at the farm, processing and retail levels
- Cattle contributed 16% of the total farm value of $49 billion in 2010-11
- The gross value of Australian cattle and calf production in 2009-10 was $7.27 billion
- Australia has 3% of the world cattle inventory and is the 8th biggest beef producer
- Australia produces 4% of the world beef supply; Queensland is the state with the highest production
- In 2010-11 Australia exported 65% of its total beef and veal production to over 100 countries.

The regional distribution of production has changed over time with a steady increase in the cattle numbers in the north of the country.

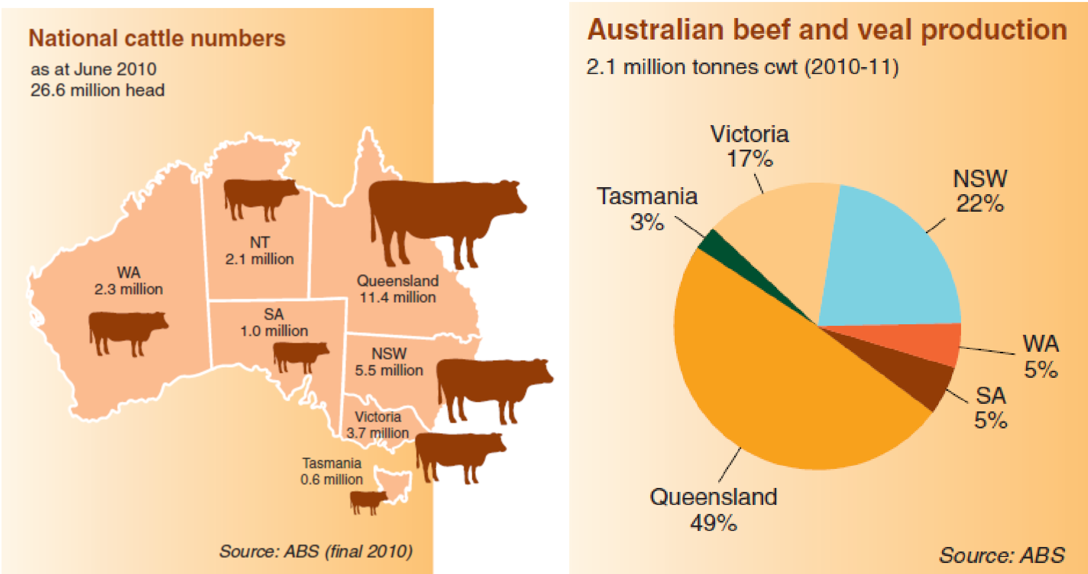


Figure 3 - Overview of the number and distribution of beef cattle and Australian beef production in 2010 (ABS 2010a, MLA 2011)

Table 1 – Breakdown of the Australian beef herd by breed (Data for 1999 NLWRA 2001)

Breed	Number ('000)	Proportion (%)
Hereford	3,874	19.2
Angus	1,687	8.4
Shorthorn	849	4.2
Murray Grey	358	1.8
Other British breed	173	0.9
European breed	121	0.6
Brahman	3,659	18.2
Santa Gertrudis	1,012	5.0
Other Tropical breed	729	3.6
British breed cross	2,165	10.7
British x European	978	4.9
Bos indicus x Bos taurus	2,964	14.7
Other types	1,578	7.8
AUSTRALIA	20,146	100.0

1.3.4 Land use and natural resources

The unsuitability of much of Australia's rangelands to sheep production, the difficulty in finding long-term economically sustainable solutions to external sheep parasites (i.e. blowfly), and the spiralling cost of labour means that the vast majority of the rangelands is suitable only for beef production. The Australian beef cattle industry occupies an area of around 200 million hectares, generally located in the inland and northern areas of Australia (Figure 4). In 1998, 28% of beef grazing lands were in southern Australia with the majority (72%) in the north of the country. Only 0.5% or 1.174 million ha of the area used for beef production was irrigated pasture. Of the northern production region of 158.5 M ha, 66% was in the pastoral zone. This is generally in semi-arid (250 – 500 mm rainfall) to sub-humid (500 – 900 mm rainfall) zones, mostly on native grasslands or savannas. Extensive grazing of beef cattle or sheep on native or naturalised pastures represents the most effective use of these largely non-arable land types for food or fibre production. In such low rainfall, low nutrient landscapes, sustainable production is characterised by low stocking rates and management that is responsive to seasonal conditions.

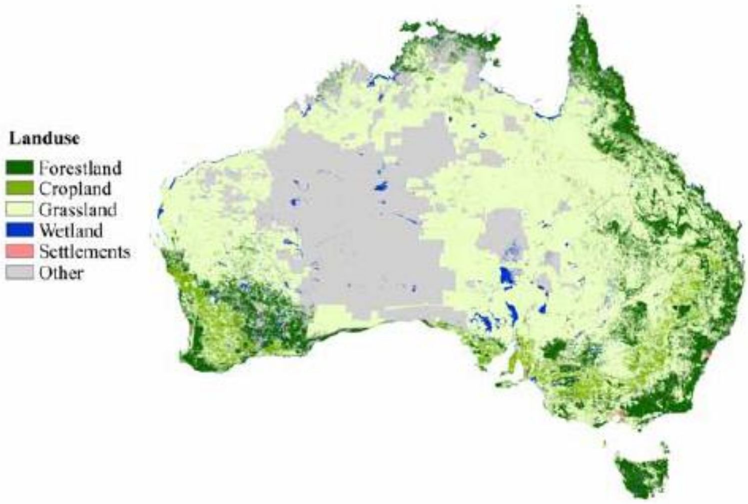


Figure 4 - Land Use in Australia 2010 (DCCEE 2012)

1.3.4.1 National trends in land use

Land use mapping by the Australian Bureau of Rural Sciences (BRS 2010) shows that in the five year period from 1996/97 to 2001/02, the area of land with natural vegetation used for production fell by 12.7 million ha. This was due primarily to an 11.6 million ha decline in grazing land. Approximately half of the rangelands lost from production was converted to cropping and half to conservation reserves. More recent statistics from the Australian Bureau of Statistics show the area under crops and the protected land area has continued to increase while non-crop farm area (predominantly grazing) has declined (Figure 5). The trend towards taking land from production to conservation is likely to increase. For example, in 2009 the Queensland government announced as part of the State's climate change policy there was an objective to increase the protected area from 8.3 M ha to 20 M ha by 2020.

In the longer term, climate change may reverse the trend towards increasing areas under cultivation with some predictions indicating that lower effective rainfall will drive conversion of more marginal croplands to permanent pastures (PMSEIC 2010). The potential for expansion or intensification of productive rangelands has also been affected by legislation by State governments to end broadscale land clearing in the past two decades, in particular in New South Wales and Queensland. Vegetation management policies may also affect the potential for sustainable intensification of production in savannas through restrictions on clearing to manage woody encroachment, regrowth and woody thickening. Stopping of traditional broadscale clearing using chemical or mechanical methods to manage woody regrowth and thickening or to offset the impact of woody proliferation by clearing remnant woody vegetation is predicted to move current tree-grass balance away from grasses and have a negative impact on livestock carrying capacity (e.g. Burrows et al. 2002).

The tyranny of distance combined with variable rainfall, poor soils and pressure on underground water supplies means that other agricultural pursuits and intensive livestock enterprises are never likely to succeed. While farming macropods and harvesting feral animals (e.g. goats) are often proposed as alternative production systems, the market signals to date suggest they will never be economically sustainable except for a very few low-income operations. In other words, the beef industry is the only real solution to ensure ongoing stewardship of the rangelands.

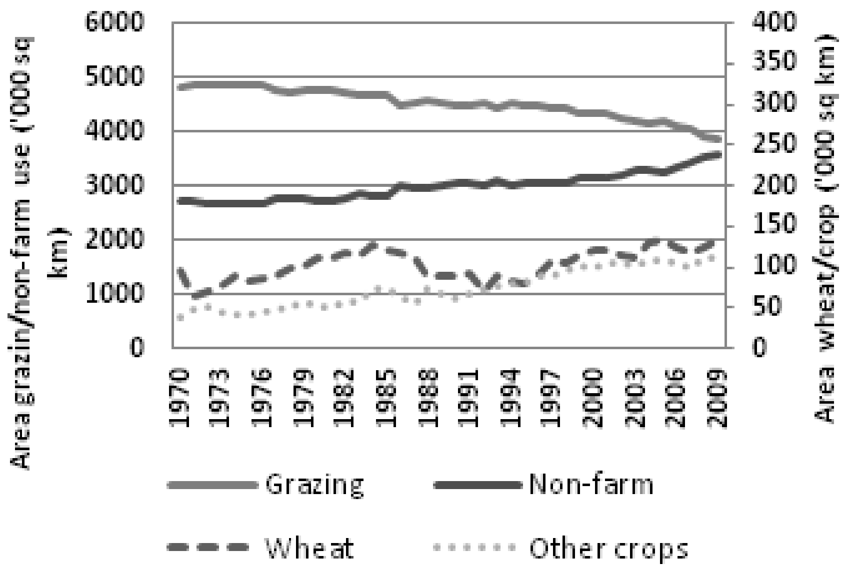


Figure 5 - Trends in land use for major agricultural production in Australia (Source of data: ABARE 2009).

1.3.5 Australia's climate

The climate of Australia which varies widely both geographically and from year to year (Figure 6, Figure 7) is a major driver of the location of agricultural activities and of characteristics such as animal breeds and feed types that strongly influence management, productivity and environmental interactions.

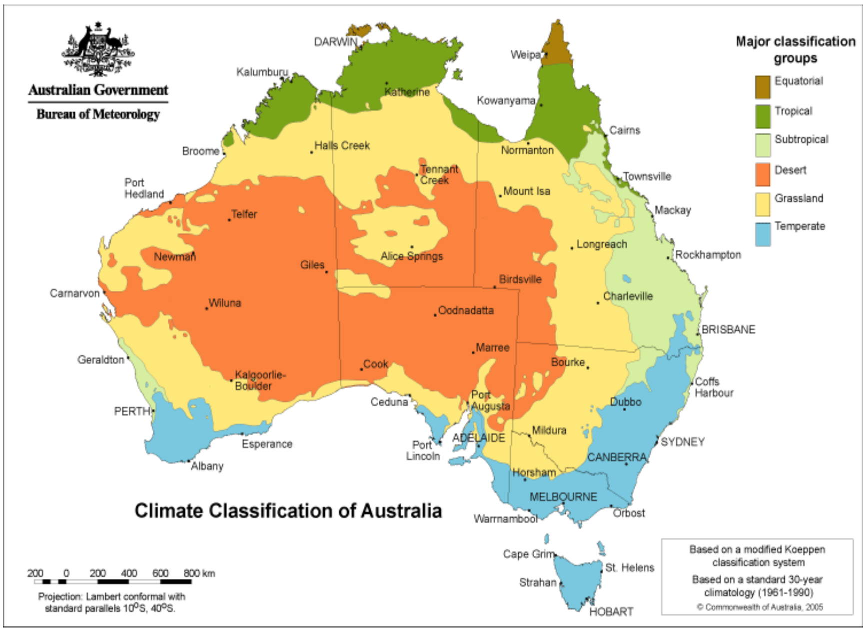


Figure 6 - Climatic classification of Australia showing the six major climate zones based on the Koppen classification. These are reflected in the ANRA beef regions used in this analysis

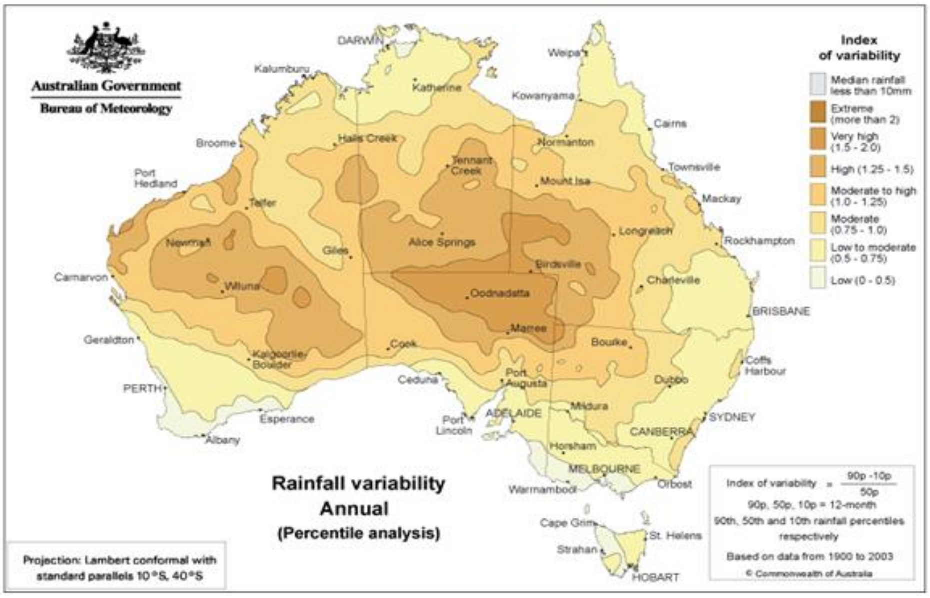


Figure 7 - Climatic variability in Australia temporally. Shows the high inter-annual variability in rainfall particularly across inland arid/ semi-arid regions

Most of Australia is arid or semi-arid, with 80% of the land having a rainfall less than 600 millimetres per year and 50% having less than 300 millimetres (Figure 8). These low rainfall levels are characteristic of the majority of beef properties (Figure 9) which extend across the continent from the tropical north to the arid and semi-arid interiors and the temperate, more fertile areas in the south-west and south-east.

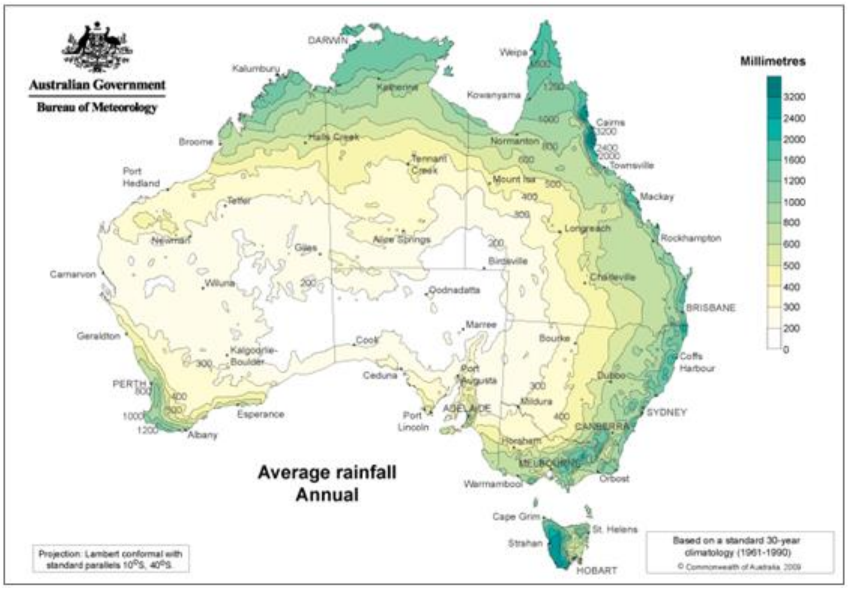


Figure 8 - Average annual rainfall for Australia

Figure 9 - Average annual rainfall for Rangelands

The rangelands where the majority of beef production occurs in Australia have been defined by ANRA as extending across low rainfall and variable climates, including arid, semi-arid, and some seasonally high rainfall areas. Extensive grazing on native pastures occurs across the rangelands while broad scale cropping and cultivation generally do not take place. The rangelands are also characterised by high inter-annual variability in rainfall and this results in turn in high variability in plant growth and hence the nutrition available for cattle (and other herbivores such as macropods). Beef producers experience this variability through the need to manage supplementation and stock movement and also through restrictions in some management options such as use of fire for improving pasture production and quality. Conversely, inappropriate management during periods of climatic extremes, particularly extended droughts, has been linked to loss of productivity and resource degradation (McKeon & Hall 2002).

In addition to the natural variability that characterises Australia's climate there is increasingly evidence of trends in key climate variables, particularly temperature. In some regions such as the south-west corner, rainfall amount and intensity have also changed significantly. These trends are influencing agricultural production and management in some regions (See Appendix 5 for more detail).

2 Resource use and GHG emissions from beef production

Beef production may affect resource scarcity (water, energy, land), resource quality (land and water degradation), atmospheric impacts via greenhouse gas emissions and air quality impacts. This report focusses primarily on greenhouse gas impacts and additionally investigates resource use (water, energy and land). In this chapter we describe the drivers of these environmental interactions for beef production and the approach to quantifying the impacts and resource use in Australia over the period from 1981 to 2011.

2.1 Greenhouse gas emission sources from beef cattle production

Australian agriculture contributes around 15% of the national greenhouse gas emissions, with the livestock industries contributing around 10% of national emissions (Figure 10, Table 2). The agriculture sector is the dominant national source of both methane and nitrous oxide, accounting for 58.0% and 75.5% respectively of the net national emissions for these two gases (DCCEE 2010a). Emissions from agriculture have been approximately stable since 1990.

The direct greenhouse gas emissions from beef cattle arise from enteric fermentation (the rumen digestive process) and from manure.

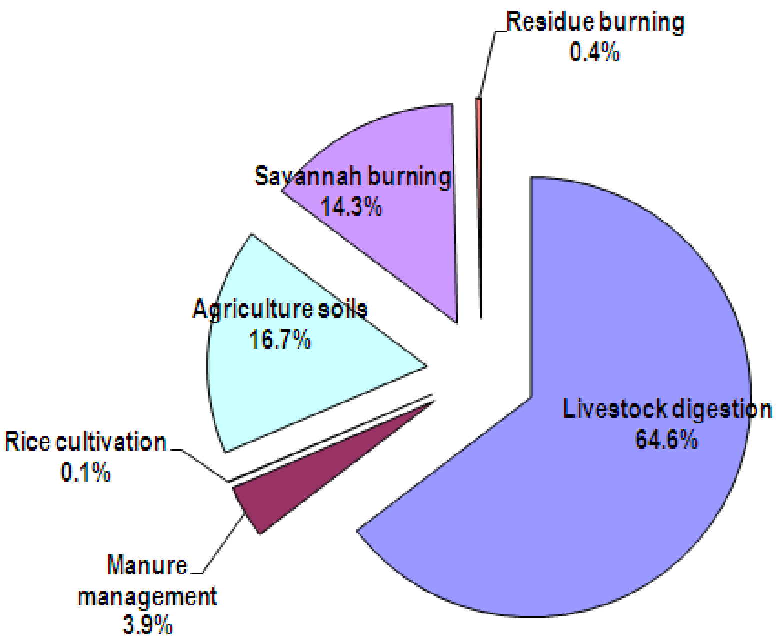


Figure 10 - Sources of greenhouse gases from agriculture in Australia (DCCEE 2011)

Beef production also produces indirect emissions, with sources including loss of soil carbon due to overgrazing, application of nitrogen fertilisers to feed grain and other upstream inputs such as chemicals and diesel, and clearing of trees to promote grass growth. Savannah burning conducted to manage woody weeds and promote pasture quality also generates emissions. As noted by the NGGI, anthropogenic fires, which have been a feature of the Australian landscape since at least 38,000 BP, replace wildfires that would occur naturally otherwise, and it should not be assumed that stopping such fires would reduce GHG emissions (DCCEE 2010a). Results are highly uncertain before 1990 when remote sensing technologies were developed to map fire scars to support national inventory reporting. From 1990 to 2001 emissions from savannah burning increased but subsequently declined significantly until 2005 when a sinusoid trend emerged. The observed trend over the past 20 years will not necessarily continue into the future as emissions are highly variable and largely reflect variations in climatic conditions. This makes it difficult to attribute changes to human activities and specifically to beef production. Consequently, the present trend analysis has not included emissions from savannah burning.

Table 2 - Breakdown of Australia's greenhouse gas emissions as estimated by DCCEE (2011) for 2009

	Emissions[1]	
	Mt CO2-e	% Aus total
Agriculture	87.4	**15.2**
Enteric Fermentation	55.6	**9.6**
Beef Cattle(inclu. Feedlot cattle)	37.8	**6.6**
Manure Management	3.3	**0.6**
Beef Cattle(inclu. Feedlot cattle)	1.1	**0.2**
Beef Cattle total	38.9	**6.7**
Rice Cultivation	0.0	**0.0**
Agricultural soils	14.6	**2.5**
Prescribed burning of Savannas	13.6	**2.4**
Field burning of agricultural residues	0.3	**0.0**

[1] (DCCEE 2011) Emissions are for 2009 and include LULUCF

2.1.1 Enteric methane

The rumen allows cattle and other ruminant animals, to break down cellulose in grasses and other forages to obtain energy and nutrients for growth. Methane is a by-product of the anaerobic digestive process (enteric fermentation). In this first stage of digestion, the forage is acted on by the complex population of microorganisms, including bacteria, fungi and protozoa, in the fore-stomach. This process releases hydrogen while producing volatile fatty acids and microbial cells containing energy and essential proteins to be made available for the growth and maintenance of the animal. In ruminants, the hydrogen is removed through the action of a group of microbes called methanogenic archaea (methanogens) that gain their energy through combining carbon dioxide with hydrogen to form methane. Hence, methane emissions provide a mechanism for preventing hydrogen build up in the rumen with resultant adverse effects on animal productivity. Strategies to reduce methane emissions must also provide for an alternative pathway to remove hydrogen.

Most of the methane that accumulates in the rumen is expelled via the mouth through belching and breathing. Microorganisms that grow and reproduce in the fermentation processes in the rumen can pass into the later stages of digestion in the ruminant providing protein and additional energy for growth. However, methane does represent a loss of energy from the animal production system with 6 to 12% of gross energy intake lost as methane. This can exceed the gross energy intake directed to live weight gain by as much as 3 – 4 times (Henry et al. 2012, Henry & Eckard 2009, Kurihara et al. 1999).

2.1.2 Manure emissions

Nitrous oxide emissions account for about 10% of global greenhouse gas emissions with about 90% derived from agricultural practices (Smith et al. 2007). About 60% of Australia's nitrous oxide emissions come from agricultural soils, where it is produced predominantly by the microbial process of denitrification with a lesser amount from nitrification. Soil nitrate levels and soil aeration are key factors affecting nitrous oxide emissions from grazing systems (Eckard et al. 2003). Hence, strategies for improving the efficiency of nitrogen cycling in animal production systems, and improving soil aeration, should also lead to lower nitrous oxide emissions. These options for reducing nitrous oxide emissions from soils are relevant to intensive production systems as described by Eckard et al. (2010).

Nitrous oxide is also produced from urine deposited by livestock on soils and from manure and effluent during storage and treatment (Castillo et al. 2000, Eckard et al. 2006). Of the dietary nitrogen consumed by ruminants, less than 30% is utilised for production, with the majority (over 70%) being excreted. Because the deposition rates are much greater than those at which soil-plant systems efficiently utilise the nitrogen, strategies for improving the efficiency of nitrogen cycling effectively also reduce nitrous oxide emissions. If animal urine in grazing systems could be spread evenly across the paddock the effective nitrogen requirement of the system would be greatly reduced but any objective of achieving this is hampered by the lack of a practical and effective means of achieving more even spread.

Cattle manure contains in the order of 16 to 24kg nitrogen per tonne. Nitrogen can occur as organic nitrogen, ammonium and nitrate with a range of transformations possible after deposition to land. Manure in extensive grazing systems results in very little nitrous oxide emissions because of the low moisture environment and dispersed spread. In manure stockpiles such as occurs in feedlots, moisture and aeration may be managed to maximise aerobic decomposition minimising nitrous and methane but leading to potentially high losses of ammonia. This will result in elevated ammonia emissions. Re-deposition of ammonia results in secondary emissions of nitrous oxide.

2.1.3 Land use change emissions from vegetation and soils

Land use change (LUC) changes the fluxes of carbon dioxide between the atmosphere and biosphere which occur naturally and in the absence of human disturbance are roughly in balance. Changes in the amount of carbon stored in vegetation and soils alters the balance. Clearing of forests for agriculture releases stored carbon to the atmosphere as carbon dioxide, with other greenhouse gases such as methane and oxides of nitrogen also being emitted if the biomass is burnt. Features of LUC emissions that distinguish this source from fossil fuel combustion or from the agricultural emissions described above are: (1) emissions from a land use change activity can occur for many years following as biomass decays slowly or as soil carbon is gradually oxidised; (2) the global warming impact is the result of the net change as some of the carbon dioxide emitted is taken up again by replacement vegetation, including woody regrowth; and (3) LUC in the form of reforestation or improved vegetation cover can result in net removals of carbon dioxide. In national inventories, LUC is reported separately to agriculture (non-CO_2 emissions). In the Australian national accounts LUC has been dominated by tree clearing for agricultural expansion or productivity increase but detailed data on the post-clearing land use are needed to attribute the clearing to a particular commodity.

The major influencing factors on decisions to change land use are production and marketing costs; the dynamics of the domestic and international markets for agricultural products; the uptake of technological change; the quality of human capital (including management capability); and social factors (SCARM 1998). At the most aggregated level it could consist of:

- **Production factors:** the suitability of climate and soils, land condition, innovations, irrigation, technologies, input costs;
- **Marketing factors:** quality, timeliness, prices, transport, population trends and consumer wants;

- **Personal factors:** motivations, cultural, knowledge, preferences, attitudes to risk and change, and skills;
- **External factors:** regulations, social changes, infrastructure, land tenure, financial/capital availability, government policies and plans.

In most developed countries, LUC is a minor or negligible contribution to agricultural product GHG emissions because clearing occurred many decades ago. Australia's land development is much younger, having occurred in the period since European settlement about 220 years ago. The most dramatic loss of biomass has been from clearing of forests (including woodlands) for agriculture. Clearing of woodlands in the drier regions was primarily for broadacre cropping or extensive grazing of sheep and cattle.

Figure 11 shows the rate of forest clearing in Australia from 1973 to 2010. Early years have a greater uncertainty because they rely on anecdotal evidence or low resolution satellite imagery. Emissions from clearing are calculated from the area of clearing and the difference in carbon stocks (vegetation and soil) between the pre-clearing and post-clearing states. If cleared vegetation is burned as was commonly the case, non-carbon dioxide gases, predominantly methane and nitrous oxide are released to the atmosphere and these must be accounted for in calculating the global warming potential in addition to the carbon dioxide. If vegetation is left to decay, the emissions occur over an extended number of years so that the emissions in any year reflect not only the clearing occurring in that year but loss of carbon as a result of past clearing. Emissions from clearing are partially offset by woody regrowth where this occurs in savannahs and woodlands. Regrowth also results in some clearing for grazing being of lower biomass vegetation compared to first-time clearing and this needs to be taken into account in calculations of net emissions.

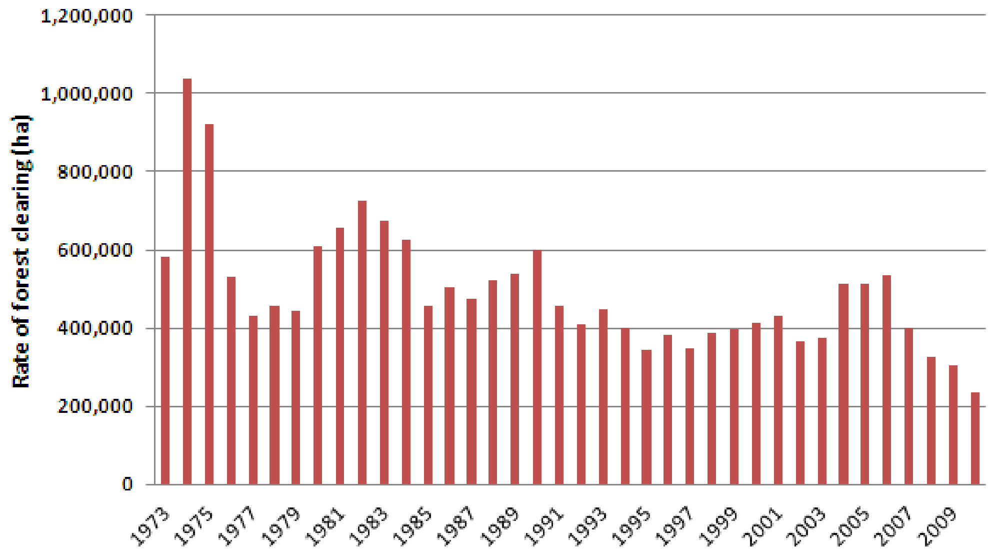


Figure 11 - Rate of forest clearing in Australia from 1973 to 2010 (DCCEE 2012)

2.2 Water use in beef cattle production

Stress on fresh water resources is a growing concern both in Australia and globally. The World Health Organisation have estimated that 1.1 billion people do not have access to improved water supply sources (WHO 2009). With a growing human population, it follows that stress on water reserves will increase dramatically in the next 30-40 years (Rockström et al. 2007). While water scarcity is a relatively difficult term to define, there is little doubt that water resources are under considerable pressure worldwide (Falkenmark et al. 1989, Glieck et al. 2009, Shiklomanov 1998). Agriculture is attributed with using 65-70% of water extracted from the environment in Australia (ABS 2006b), which is similar to the situation globally. Of the water used for agriculture, most is used for irrigation, with smaller amounts used for livestock.

While Australia has adequate water resources nation-wide, not all water resources are easily accessible to areas of high demand, and competition for water resources is one of the most severe resource allocation issues facing the country. Water 'use' is an ambiguous term that may include both consumptive (i.e. evaporative) and non-evaporative uses (i.e. cleaning water that is 'used' but then released to the environment). Evaporative use, or consumptive water use, directly limits short term availability to other users. While evaporated water eventually returns via precipitation, the timing and distribution of rainfall is variable. Determining the amount of water used for consumptive and non-consumptive purposes in any production system requires use of a water balance at different stages in the supply chain (Bayart et al. 2010). Non-evaporative uses may be classified based on the degree of quality degradation, and how suitable the water is for a range of subsequent users (Boulay et al. 2011). It is important to note that, where water flowing from a system is degraded in quality but still suitable for other users, it may be considered a flow rather than a use, despite a change in quality. However, uses that result in degradation of water quality should be clearly described.

There is also a clear relationship between land transformation (land use change) and hydrology. Mila I Canals et al. (2009) suggests that differences in the water balance between the current land occupation and the 'reference' land occupation (i.e. open forest etc.) be attributed to the production system. Australian research consistently points to higher runoff rates (i.e. water generation) following land transformation from forest to cropping or pasture (Brown et al. 2005). This aspect has not been investigated in detail in the present study, but must be kept in mind when considering the full range of impacts from land use change practices.

2.2.1 Water requirements for beef cattle

Water requirements of cattle vary greatly depending on the moisture content of the feed, the climatic conditions and the physiological state of the animal. For example, a lactating animal requires substantially more water than a non-lactating animal and animals on a lush pasture may not require any drinking water at all. Distance between watering points influences frequency of drinking and amount of water consumed. While the daily intakes of animals in the intensive livestock systems is able to be calculated relatively accurately, in practice water use it is rarely measured in the rangelands. Animals drink until their thirst is satisfied and as long as there is adequate water available in the waterhole, dam or trough, few farmers are concerned with the amount consumed.

Work performed on water intakes in grazing animals is quite limited. The text "Nutrient Requirements of Domestic Ruminants" (CSIRO 2007) reports that the daily requirements of cows in the in the Mediterranean climate of the Eyre Peninsula of South Australia in 1978 was 90 ml/kg over a 3 year period. Research at Rockhampton in 1968 by Springell reported average daily intakes over a 13 month span amounting to 105ml/kg body weight. Drinking water intake in this study was based on the equations outlined by Ridoutt et al. (2011), based on CSIRO (2007). This equation is based on temperature, dry matter intake and accounts for the moisture content of feed.

2.2.2 Water supply sources and dynamics for beef cattle production

Water supply varies considerably across different parts of Australia. Capture of surface runoff in earthen dams is the most widespread method of delivering water for grazing livestock in Australia, though in arid regions this is not generally reliable enough to sustain livestock through drought periods. In many regions, creeks and rivers provide important watering points. Alluvial bores are common in many parts of Australia, and generally draw from shallow, local aquifers that are recharged from surface water. In the central and northern parts of Australia, cattle production is underpinned by water supplied from the Great Artesian Basin (Figure 12). Access to this water source has been critical to the development and expansion of grazing into central and northern Australia. While water quality is important in maintaining satisfactory productivity, cattle can utilise water of a quality that is unsuitable for human consumption and unsuitable for most other agricultural purposes. Water containing total soluble salts (TSS) of up to 5,000 ppm and <600 ppm of Mg is suitable for sheep and cattle of all ages while water containing 5,000 – 10,000 ppm TSS and <600 ppm MG may be suitable for grown cattle and sheep, but not young stock or lactating animals (CSIRO 2007). These quality considerations are relevant when assessing cattle water use in Australia, as much of the water utilised in rangeland regions is of poor quality and could not be considered usable for most other purposes, such as human consumption.

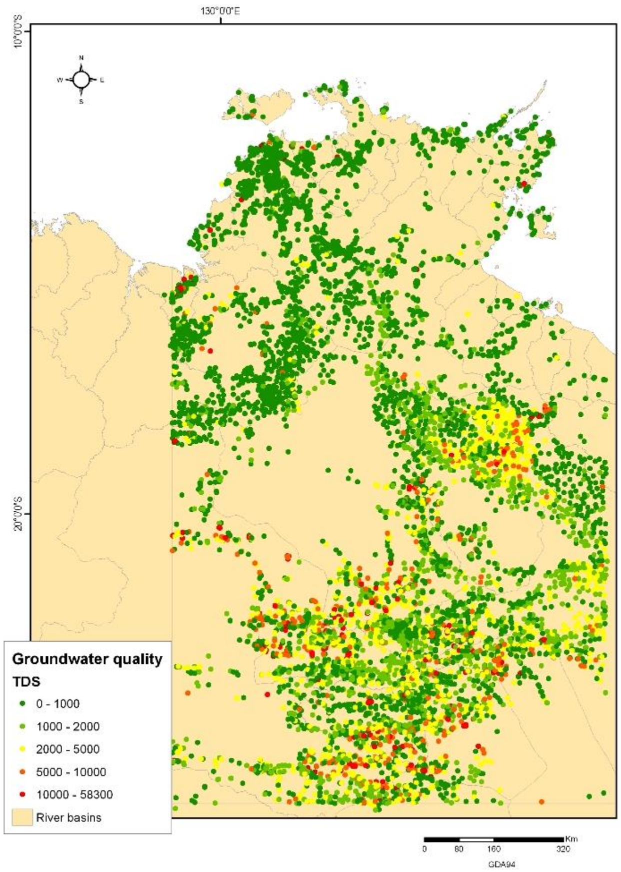


Figure 12 – Quality of water from bores used to supply drinking water to cattle in Queensland (Kurup et al. 2011)

2.2.3 Irrigation water used for beef cattle

In the south eastern parts of Australia, irrigation is used for pasture production, fodder and grain production. Irrigation requires large volumes of water which can lead to substantial contributions on a national level. From 2005-06, the ABS have reported irrigation water used for grazing meat cattle distinct from other pasture irrigation uses. Some other categories may contribute to water use in the supply chain (i.e. for the production of feed inputs to grazing or lot feeding). The ABS does not collect data relating to on-farm dams used for livestock drinking water and does not take into account drinking water from creeks or rivers. It is possible some bore water used for livestock is included in the livestock data. Australian water use data for a number of agricultural industries are presented in Figure 13.

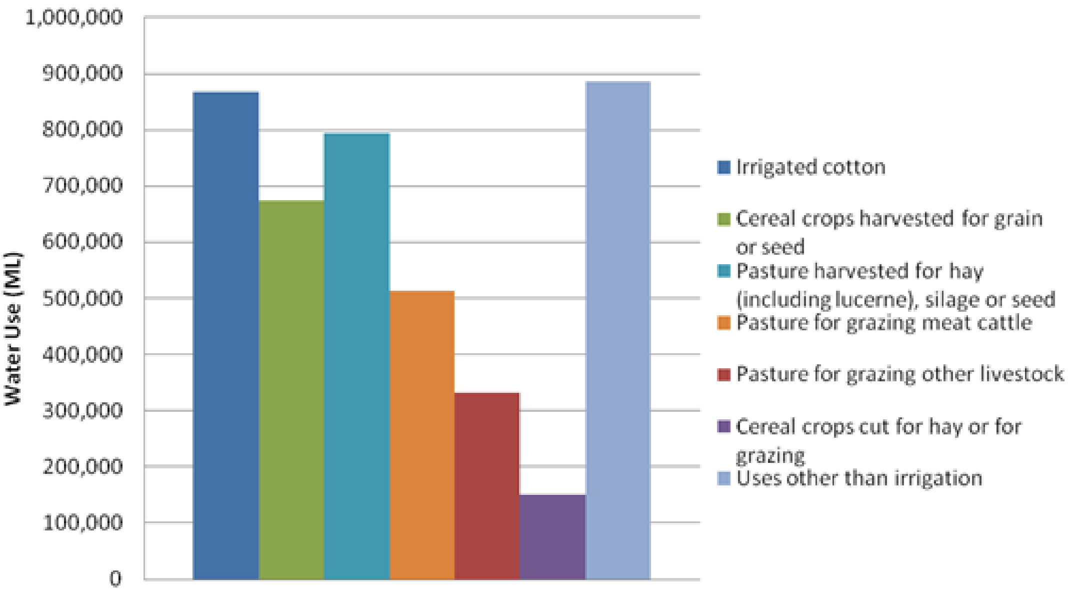


Figure 13 – Water Requirements for a number of agricultural commodities (ABS 2008c)

2.3 Land use for beef production

Land, particularly arable land, is a limited resource globally and land use is included in analyzing the environmental implications of a product as the ‘land use’ or ‘land occupation’ area required to produce a product. For beef production the most important components of land use is the pasture/grassland area for grazing beef cattle and area of arable land used to produce feed. Land use may be expressed as simply the area for production or disaggregated using an indicator of land quality, e.g. arable and non-arable, or on an index of its productive capacity such as Net Primary Productivity (NPP).

For agricultural products assessment of the area and type of land needed for production is an important indicator of resource use and, combined with data on GHG emissions and water use, assessing land occupation contributes to reducing the risk of unintended trade-offs in environmental assessment (Ridoutt et al. 2011). To be meaningful, a measure of land use should take into account the level of landscape modification and the demand for alternative use. An area of semi-arid land with near intact ecosystems used for extensive livestock production is not equivalent to the same area of land used for intensive cropping. Categorisation of agricultural land based on a measure of quality or utility is an initial step in understanding the resource implications of food and fibre production. Indicators of land occupation and land transformation have been applied in some LCA studies but there is no consensus methodology at this time. Characterisation factors for land use (land occupation) are under development by the United Nations Environment Programme and the Society of Environmental Toxicology and Chemistry (UNEP-SETAC) Life Cycle Initiative (Koellner et al. 2013).

2.3.1 Land use in Life Cycle Assessment studies

Differentiation of occupied land for agriculture is important as a measure of the 'value' of the occupied land in terms of its potential for alternative land use or provision of some ecosystem services, e.g. recreation use, if taken out of production. Carbon sequestration or biodiversity potential are often considered values and, of these, carbon sequestration potential is easier to quantify and, therefore, more commonly used.

Land occupation in reported LCA studies has been expressed as:

- total area used for production, e.g. ha/kg product;
- land area disaggregated by land type, e.g. arable and non-arable land;
- land area classified by a measure of its quality or productivity, e.g. by Net Primary Productivity (NPP) class or biome type.

Data sources used for assessing land occupation include FAO statistics, national data and satellite imagery. Because impacts on biodiversity, ecosystem services and potential for productivity can be regionally specific, combining separated land areas may require characterisation factors to be applied. In some cases this may involve ascribing production to one or more countries from which products are imported (Mila i Canals et al. 2012). In terms of assessing potential for food and fibre production or for carbon storage, three characteristics are most important: mean annual precipitation, mean annual biotemperature (the mean of all temperatures above 0°C because below this temperature plants are generally dormant), and ratio of annual potential evapotranspiration to rainfall (Holdridge 1947). These are reflected in estimates of Net Primary Production (NPP). Koellner et al. (2012) developed a classification of land use and land cover based on four levels of detail. However, for most agricultural products quantifying and interpreting land occupation in LCA studies retains a high uncertainty and degree of subjectivity (e.g. Mila i Canals et al. 2012).

Although consensus appears a long way off, in efforts to provide more meaningful interpretation of land use in in LCA studies, there have been several alternative approaches published for different studies. For example, Schmidinger and Stehfest (2012) attributed a 'missed potential carbon sink' resulting from land occupation to agricultural products, including beef. In practice this system is highly dependent on the accuracy of the spatially explicit carbon cycle model used to estimate the missed potential carbon sink and the potential for error is illustrated by their published results for land for Australian sheep and goat production which has the same potential carbon sink as that for dairy (0.64 kg CO_2/m^2/year). This study gives beef a much lower value (0.01 kg CO_2/m^2/year). The calculation of a 'biodiversity damage potential' (BDP) (de Baan et al (2012) provides broad global characterisation, but the authors emphasise the need for regionalised data before it can be used as the basis for recommendations on land management practices.

Brandao and Mila i Canals (2012) propose use of change in soil organic carbon as an indicator of the impacts of land use on the 'biotic production potential' (BPP). BPP refers to the conditions of land that determine its inherent ability to produce and sustain biomass (food, feed, fodder, wood, fibre, energy, medicines, ornamentals) at current productivity levels through the provision of water, nutrients, air and a stable physical support for plant roots. There is definite value in understanding the ability of a landscape to sustain future biomass (and carbon) sequestration, but the data required to assess the important soil organic matter status are seldom available at paddock scale resolution.

In contrast to BPP, Net Primary Production (NPP) refers to the potential production resulting from a specific land use and can allow for additional inputs such as organic or industrial fertilisers. Net Primary Production (NPP) has been widely used as an indicator of ecosystem function (e.g. Schläpfer & Schmid 1999). NPP represents the net production of organic carbon by plants in an ecosystem. It has biological relevance for beef since carbon compounds fixed in plants for grazing or browse provide the substrate and energy (and enteric methane emissions) for cattle and also provides links between the biosphere and the climate system through the global cycling of carbon, water and nutrients (Roy et al. 2001). In a managed system NPP thus indicates the quality of an area of land to produce food and fibre.

In summary, land use is widely recognised as having environmental relevance but remains too difficult to quantify in LCA studies to ensure consistency or to provide a basis for comparative assertions. Interpretation and communication of land use as an indicator of resource stress remains challenging. In the absence of a consensus approach, we conclude that the use of area of land occupation characterised using a measure of the 'quality' of that land, e.g. non-arable vs [potentially] arable provides a defensible initial indicator of the environmental impact of agricultural production consistent with current data availability from sources such as FAO. Analysis of trends over time as in the current study on Australian beef is further complicated by movement of land parcels between production systems, both livestock and crops) or between production and the national reserve system within the study period, either because of market or climate drivers.

2.4 Analysis of beef production in the Australian environment

As discussed in Chapter 1.3, the beef cattle and sheep industries have been, and continue to be an important part of the Australian economy and the shaping of Australia's landscape. The interactions of beef production with Australia's agro-ecosystems has been variable over time and space and analysis of resource use and GHG emissions needs to take these differences into account but the level of disaggregation is constrained by the availability of reliable regionally-specific data and the additional value in finer-scale analysis taking into account the large number of calculations needed for each individual region. Figure 14 and Figure 15 show the distribution of beef and sheep in the baseline year (ca 1980) and in 2010, respectively.

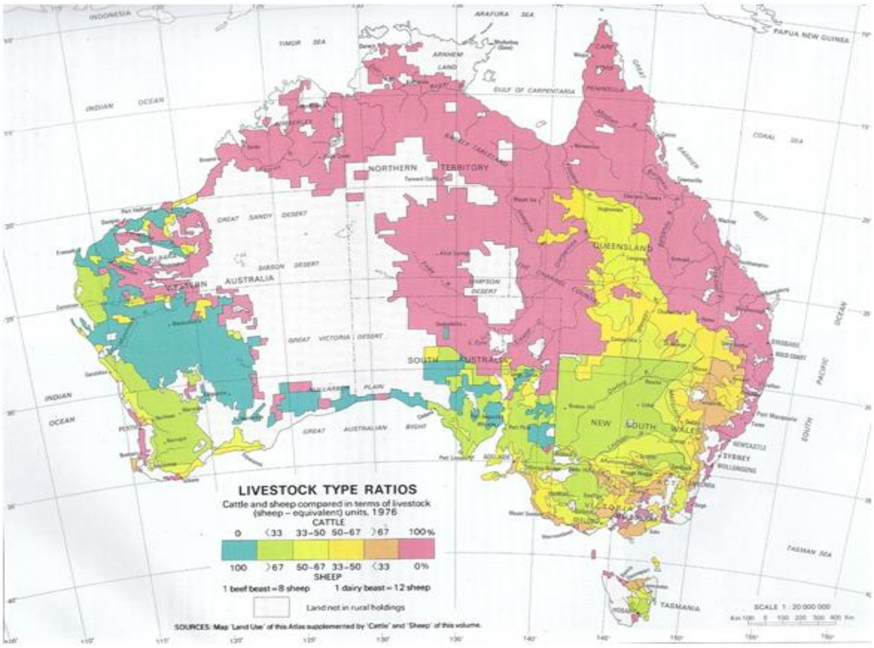


Figure 14 - Distribution of sheep and cattle in the rangelands in 1976 provide a baseline for the current trend analysis for 1981 - 2011 (NFF 1986)

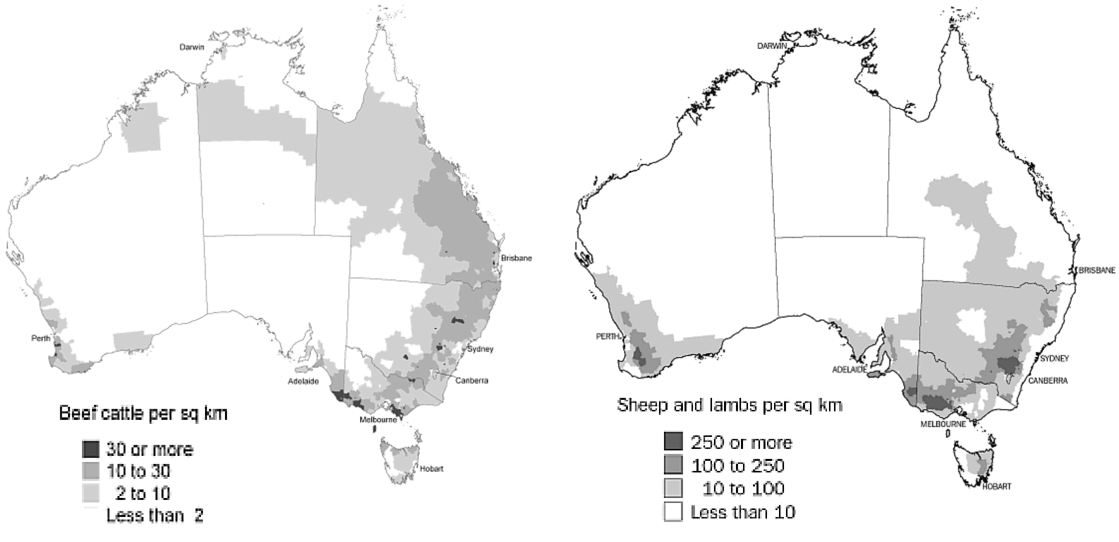


Figure 15 - Density of beef cattle (left) and sheep (right) in Australia. Source: ABS based on Agricultural Census data at the Statistical Local Area level for 2000-01 (www.abs.gov.au accessed Nov. 2013)

2.4.1 Approach to regional disaggregation of Australian beef production

Development of the Australian beef industry has not been uniform across the country. It is appropriate to examine production according to broad zones to reflect the bio-geographical, climatic and social variations influencing the industry and its impact on the environment (Figure 16). Several alternatives for disaggregation of the industry appropriate for analysing development and impacts of the national beef herd and for collecting data and production statistics relevant to the 30 year period of analysis have been reported. For implementing the current project, the trade-off between capturing regional variations and the magnitude of the modelling exercise and spatial scale of data availability was a necessary consideration. A decision was made to use the 6 beef cattle regions defined in the Australia National Resources Atlas (ANRA) as a reasonable and practical basis for the analysis of trends in environmental impacts of beef production (see Figure 17). We modified these regions, by dividing the northern region into two (see Figure 18) in order to address differences in climate and pasture conditions in the large northern region. ANRA arose out of the National Land and Water Resources Audit and, while no longer maintained, the audit is the most comprehensive assessment of Australia's resources relevant to agricultural and the production break-down is based on climatic zones (Figure 16).

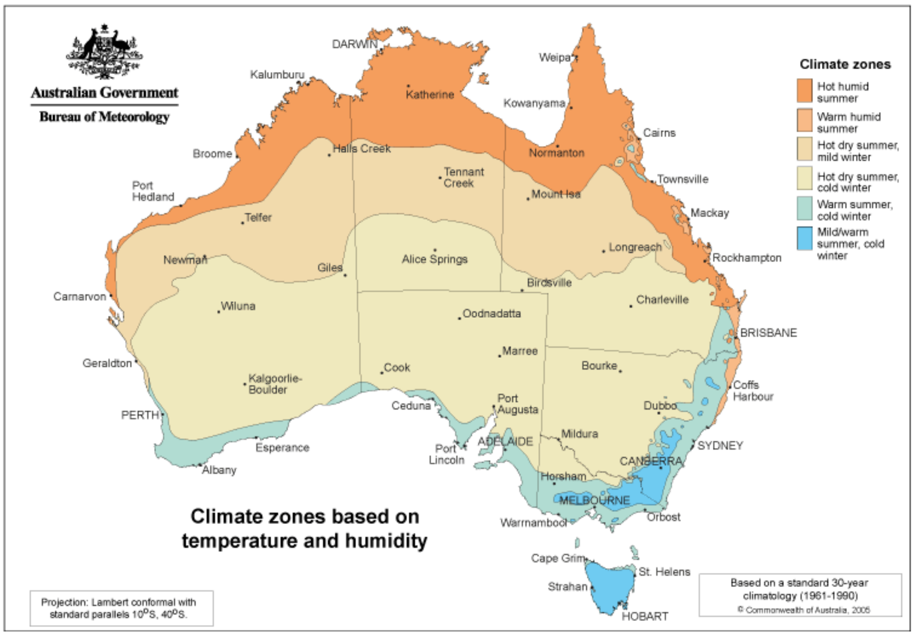


Figure 16 - Climate zones in Australia based on temperature and humidity (BOM 2012)

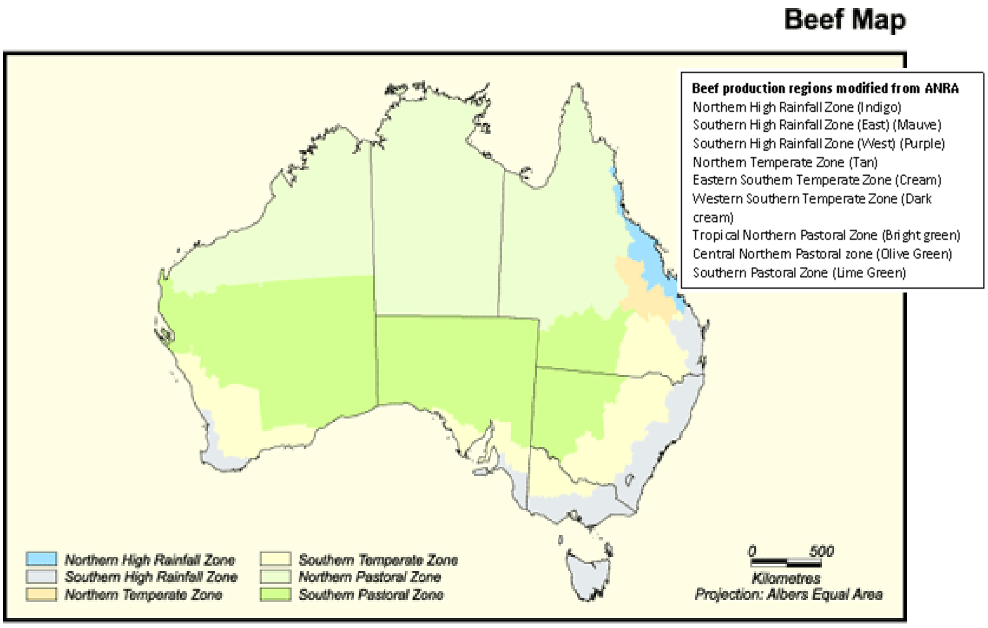


Figure 17 - Regional disaggregation of beef production based on ANRA Beef Regions

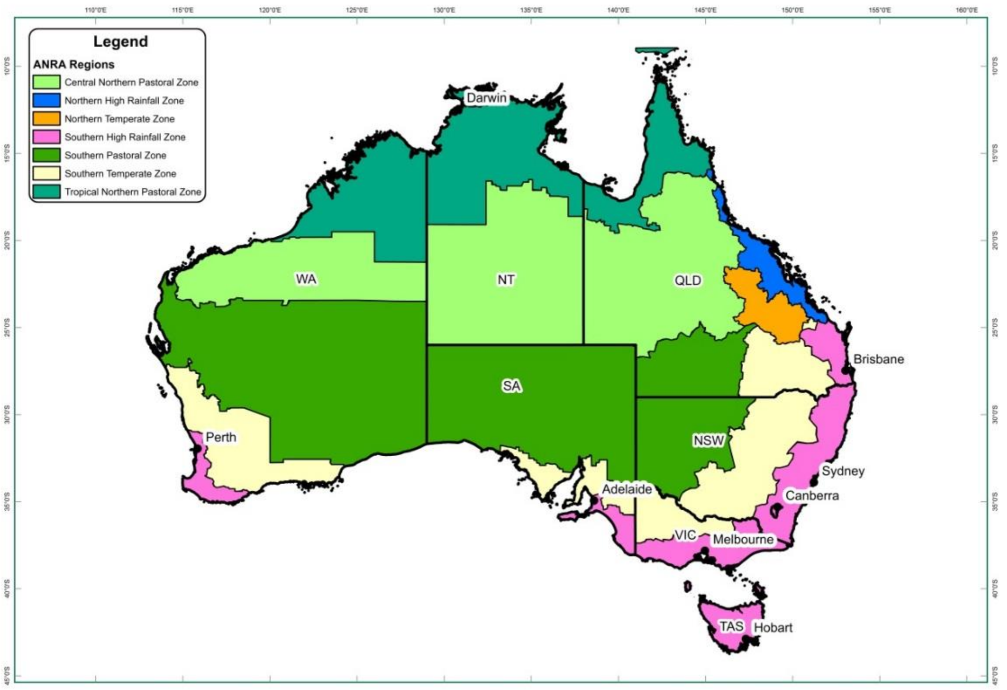


Figure 18 – Modified regional disaggregation of beef production – Based on ANRA Regions amended to better reflect the geographical and climatic production system differences

The National Land and Water Resources Audit (2001) provides a snapshot of the beef industry in 1999, the year statistics were collected. In that year, the proportion of Australia's beef area within each of the ANRA regions is shown in Table 3.

Table 3 – Proportion of Australia's beef area in each of the ANRA beef production regions in 1998

Region	Area(ha)	% of Australian beef area
Northern Region	158,504,422	72%
High Rainfall zone	6,634,626	3%
Temperate zone	6,304,595	3%
Pastoral zone	145,565,201	66%
Southern Region	61,196,364	28%
High Rainfall zone	7,832,294	4%
Temperate zone	9,044,788	4%
Pastoral zone	44,319,282	20%
AUSTRALIA	**219,700,786**	**100%**

2.4.1.1 Modified ANRA Divisions used in this project

A summary of the characteristics of beef production in each of the six regions is given below and more detail from the NLWRA report is provided in Appendix 5. We note here that despite the status of the Audit, we found that the statistic published were not consistent with ABS herd data (the sum of cattle numbers from the NLWRA are considerably greater than has ever been reported by the ABS).

Northern High Rainfall zone

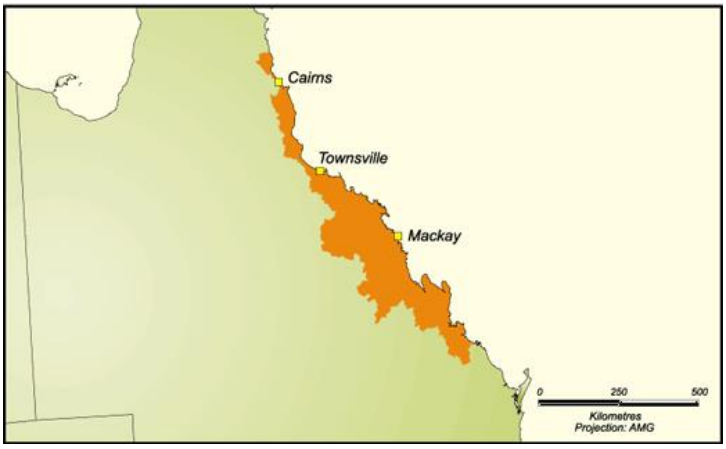


Figure 19 - Location of the Northern High Rainfall zone.

The beef industry's Northern High Rainfall zone stretches from Cairns to near Rockhampton (Figure 19). Beef cattle are grazed over 6,634,626 hectares of land, with a relatively limited number of feedlots in this region. 30% of the pasture in this region are sown or introduced, and 70% of the pasture is native or naturalised.

The Northern High Rainfall zone experiences a tropical and subtropical climate, where pasture growth depends upon conservation of soil moisture from variable rainfall. The climate is described as hot humid with dominant summer rainfall. Enterprises in this region average approximately 9,076 hectares in size and produce beef for domestic markets. Beef cattle typically graze sown pastures in this region. Weeds have been identified as the most significant form of degradation along with soil structure decline and water erosion. The industry is implementing management practices to meet these regional challenges.

Northern Temperate Zone

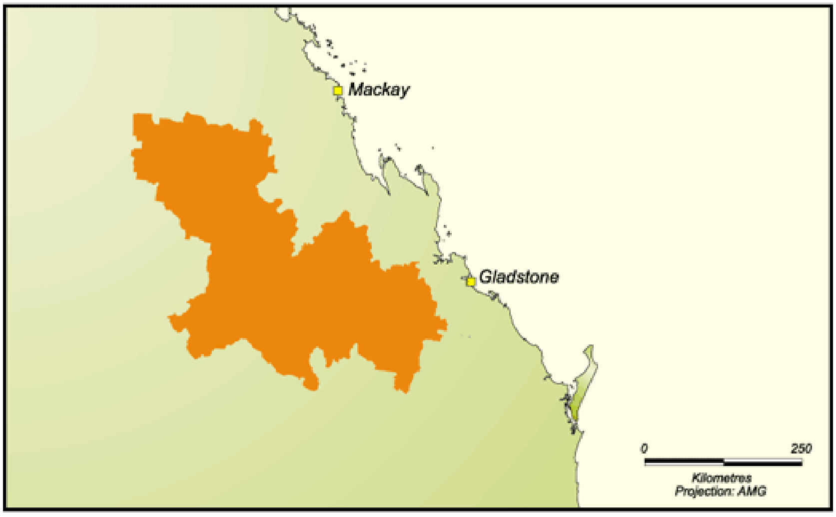


Figure 20 - Location of the Northern Temperate zone

The beef industry's Northern Temperate Zone stretches from inland of Mackay to inland of Gladstone (Figure 20). Beef cattle are grazed over 6.3 million hectares of land. 4% of the pasture in this region are sown or introduced, and 96% of the pasture is native or naturalised.

The Northern temperate zone experiences a tropical and subtropical climate, where pasture growth depends upon conservation of soil moisture from variable rainfall. The climate is described as hot, dry summer with cold or warm winters with mostly summer rainfall. Enterprises in this region average approximately 11,255 hectares in size and produce beef for foreign and feedlot markets. Beef cattle typically graze sown pastures in this region. The beef industry in this region is geographically spread down the central inland areas of Queensland. Weeds have been identified as the most significant form of degradation in this region.

Northern Pastoral zone

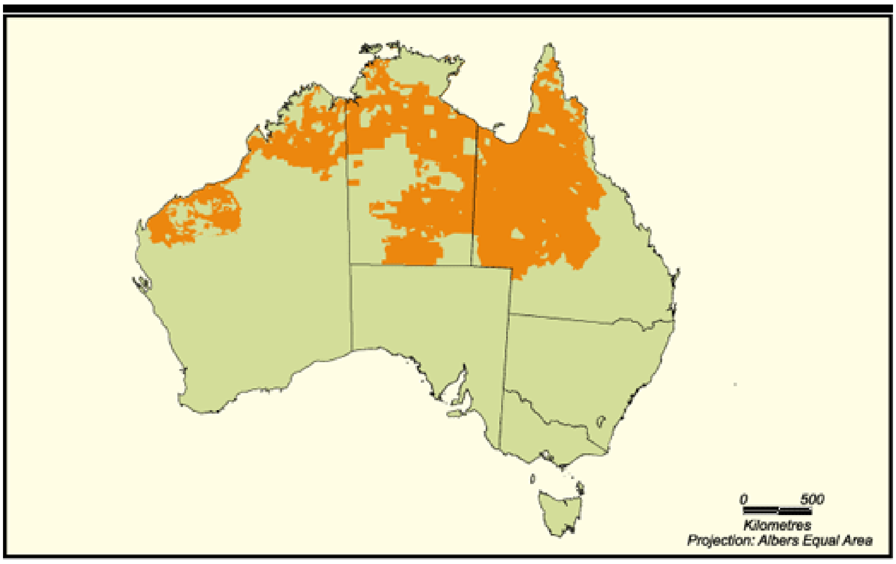


Figure 21 - Location of the Northern Pastoral zone

Note: In this project, the ANRA Northern Pastoral zone was split into:

1. Tropical northern pastoral zone including the Kimberley region of Western Australia, the northern tropical savannah regions of the Northern Territory and Queensland (the band around the Gulf and the Cape); and
2. Central northern pastoral zone including the Pilbara region of Western Australia, southern more arid rangelands of Northern Territory and central west of Queensland.

The beef industry's Northern Pastoral Zone stretches from Cape York, around the gulf and into the Kimberley region (Figure 21). Beef cattle are grazed over 145.5 million hectares of land. There are very few feedlots in this region.

The Northern Pastoral Zone experiences a tropical and subtropical climate with a monsoonal rainfall effect in the northern regions while extreme variability in rainfall is experienced in the Pilbara and arid regions of central Australia. The climate is described as hot, wet and humid in the north with extended dry spells from April to October ranging to a much drier and more variable rainfall in the centre.

Enterprises in this region are substantial in size, mainly constituting pastoral cattle enterprises. Some localised areas support a limited range of grain crops. Enterprises in this region average approximately 114,626 hectares in size and produce beef for mainly foreign markets.

Beef cattle typically graze native pastures in this region. Weeds have been identified as the most significant form of degradation. Native animal population grazing pressures (e.g. kangaroos), combined with pest populations such as feral animals and woody weeds, affect the production capacity of the pastoral systems to maintain adequate feed sources. In response, landholders in south west Queensland have prepared a set of best practice guidelines on Total Grazing Pressure (TGP) that includes both production and landscape function related management responses. The beef industry in the zone is geographically remote and in all districts across the zone, beef is the dominant industry. Climatic and soil quality constraints limit other land uses. In localised areas, some grain production occurs as a supplementary feed source.

Southern High Rainfall Zone

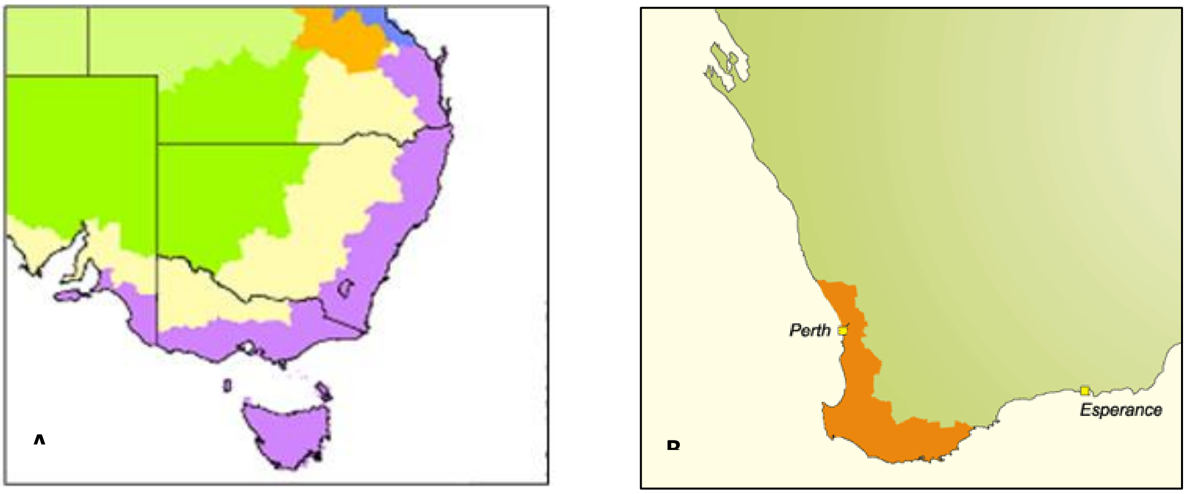


Figure 22 – Location of the Southern High Rainfall Zone (east – A and west – B)

The beef industry's Southern High Rainfall Zone stretches from north of Bundaberg, east of the Dividing Range and around the eastern seaboard to South Australia (Figure 22). Beef cattle are grazed over 7,832,294 hectares of land, with the majority of feedlots located in the northern districts of the zone. 39% of the pasture in this zone are sown or introduced, and 61% of the pasture is native or naturalised.

The Southern High Rainfall Zone experiences a range of climates including tropical, subtropical and Mediterranean. Pasture production depends upon conservation of soil moisture from generally variable rainfall. Enterprises in this region are relatively smaller, and average approximately 720 hectares in size and predominantly produce beef for domestic markets. Beef cattle typically graze sown pastures in this region.

Weed infestation, water erosion, soil acidity and surface waterlogging have been identified as the most significant forms of degradation. The general intensive nature of agriculture and urbanisation within this zone results in natural resource management issues such as irrigation salinity, weed infestation, soil acidity and water logging being difficult to manage.

Southern Temperate zone

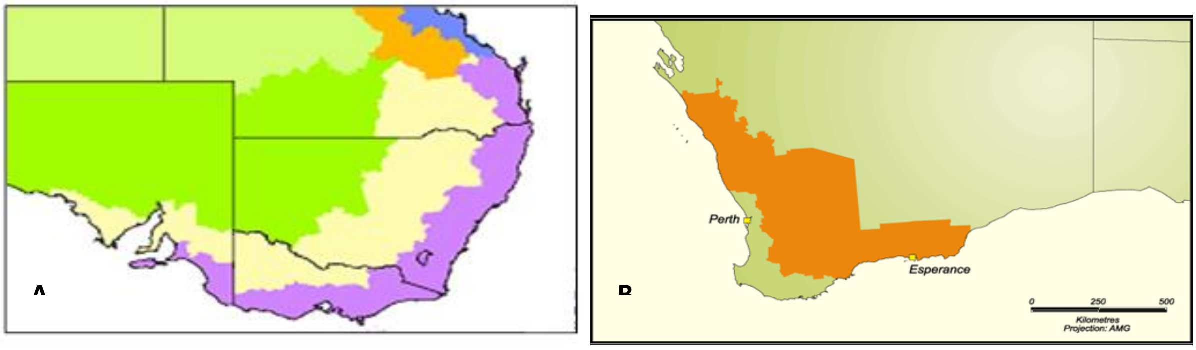


Figure 23 – Location of the Southern Temperate Zone

The beef industry's Southern Temperate Zone stretches from inland Queensland south of around Biloela, through into the Murray Darling catchment and into southern South Australia (Figure 23). The majority of the feedlots in the industry are operating within this zone due to the relative close position to feed/grain sources and adequate, reliable water supplies. Cattle are grazed over 9,044,788 hectares of land. 2% of the pasture in this region are sown or introduced, and 98% of the pasture is native or naturalised.

The Southern Temperate Zone experiences generally subtropical and Mediterranean climatic conditions, where yields depend upon conservation of soil moisture from variable rainfall. The climate is described as temperate, with hot dry summers, and cold winter regions with uniform winter and variable summer rainfall. Enterprises in this region average approximately 1,825 hectares in size and produce beef for domestic and export markets.

Beef produced in the zone typically forms part of mixed farming systems and/or mixed farming regions. The majority of the zone falls within the Murray Darling Basin catchment, and this catchment is the most intensively developed catchment agriculturally in Australia. Beef is produced alongside areas supporting grains, horticulture, cotton and dairying land uses. The general intensive nature of agriculture with many of the districts within the zone results in natural resource management issues such as dryland and irrigation salinity and weed control that are difficult to manage. The less intensive districts face environmental issues such as stream bank stability and wind erosion. Most of Australia’s irrigation is also in this zone.

Southern Pastoral zone

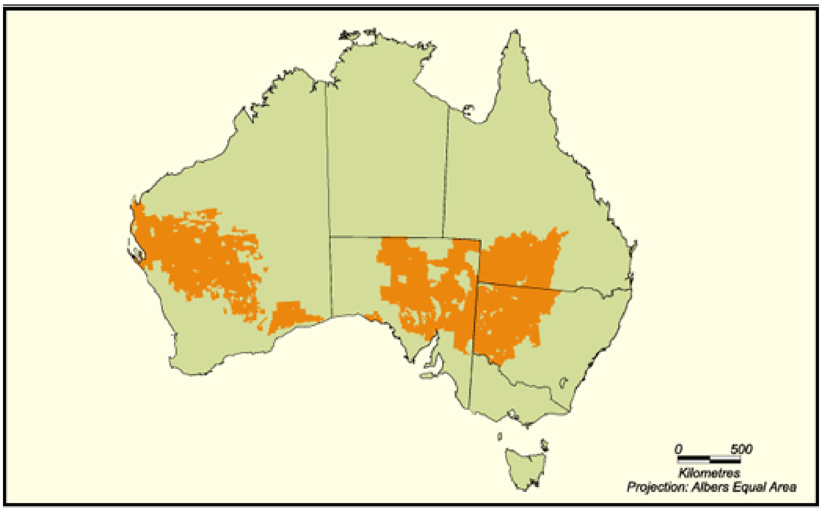


Figure 24 - Location of the Southern Pastoral zone

The Southern Pastoral Zone stretches from about Bourke in central New South Wales, across central Australia and into central Western Australia (Figure 24). Beef cattle are grazed over 44,319,282 hectares of land, with only occasional feedlots that occur in localised areas. The Southern Pastoral Zone experiences an arid climate, with hot dry summers and cold winters, and mostly uniform low winter rainfall. Yields depend upon conservation of soil moisture from low rainfall. Enterprises in this region are large in area, averaging approximately 225,558 hectares in size due to the harshness of the climatic constraints. Enterprises in this region and produce beef for domestic markets.

Beef cattle typically graze native pastures in this region. Beef produced in this zone typically forms part of mixed pastoral systems with the sheep industry. The fragility and vastness of the landscape and extensive nature of pastoralism within the zone results in natural resource management issues such as wind erosion and weed/pest control being difficult to manage. Beef and wool producers of the Western Division of New South Wales are addressing environmental challenges that stem from the integration of their production systems into these landscape systems. Native population grazing pressures (e.g. kangaroos), combined with pest populations such as rabbits and woody weeds affect the production capacity of the pastoral systems to maintain adequate feed sources. In response, landholders in this region have a set of best practice guidelines based on Total Grazing Pressure (TGP) that includes both production and landscape function related management responses.

2.4.2 Data driven alternative scale of analysis

2.4.2.1 Land use change for beef production

Review of all accessible data resources showed that no single source gave the coverage or temporal and spatial disaggregation needed for assessment of carbon stock change (and hence greenhouse gas emissions) for the 5 year time periods explicitly for ANRA regions that could in any way be confidently matched to the beef production data and estimates of emissions. Attempts to combine sources of information highlighted significant conflicts and limitations in data. Appendix 5 describes some of the analyses undertaken and why the sources were not sufficiently robust to incorporate in this project.

It was concluded that the most defensible approach was to use a top-down approach based on national inventory data in combination with high quality state data for Queensland (the state where most clearing has occurred over the analysis period) to give the area of clearing, post-clearing land use and vegetation biomass cleared. A limitation of these data is their shorter period, being available only from 1990 (Figure 25). These data from the National Carbon Accounting System (NCAS) using satellite imagery and modelling approaches for the FullCAM resource and Statewide Landcover and Trees Study (SLATS) data, respectively, were supplemented with data for 1981-1990 based on earlier national greenhouse gas inventory reporting (AGO 1998). Attribution of clearing to beef production relied on credible assumptions based on expert opinion.

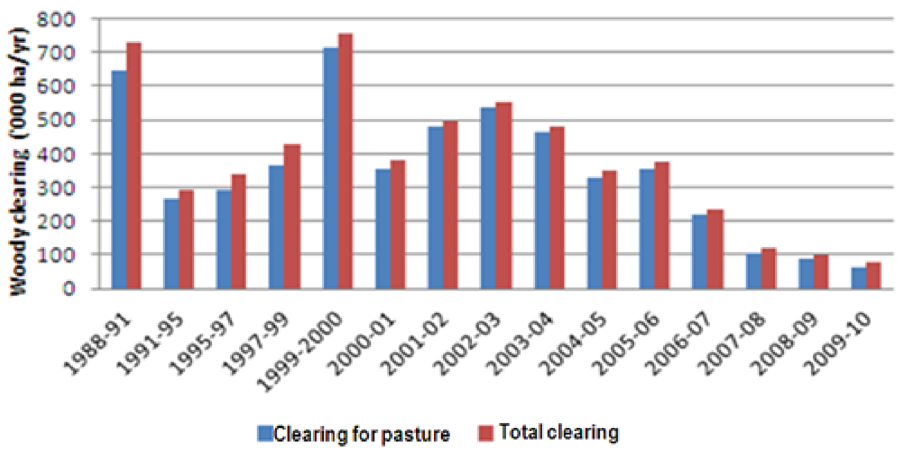
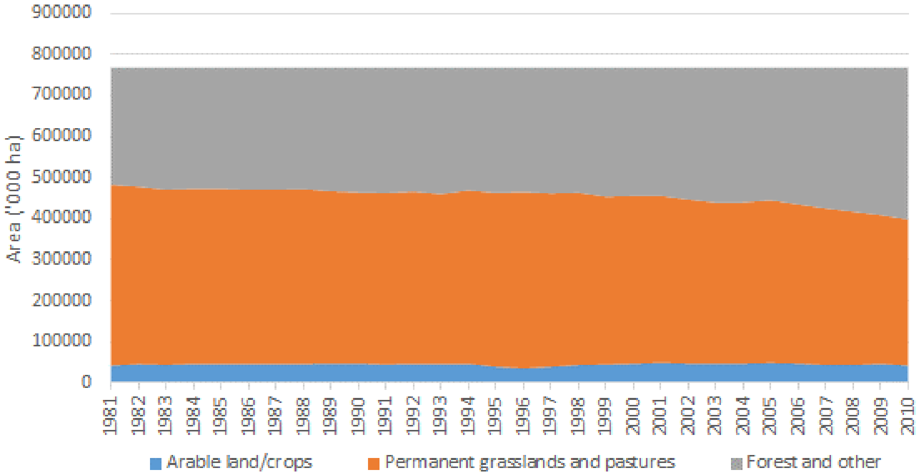


Figure 25 - Extent of clearing in Queensland for the period 1988-2010 (DSITIA 2012)

The trend analysis for deforestation was conducted on a State basis rather than ANRA regions and because of the different spatial resolution and higher degree of uncertainty LUC GWP has been reported separately to the livestock emissions. The results are considered a reasonable representation of change over time. LUC emissions also arise from loss of soil carbon during the ongoing cultivation of land for crop production. With the increase in grain feeding of beef cattle a proportion of carbon dioxide from oxidation of soil carbon and loss to the atmosphere as carbon dioxide should be included in the GWP for beef produced. Data on area of coarse grain production, yield and feed requirements for rain fed cattle provide a national estimate.

National production and resource data (FAOSTAT) provide a time series of data that enables a reasonable assessment of land use for beef production in Australia and its change over time.



shows the change in total head of sheep and cattle over time expressed as DSE as a broad indicator of resource demand. Figure 27 shows that the area under permanent grassland and pasture has declined over the period since 1981.

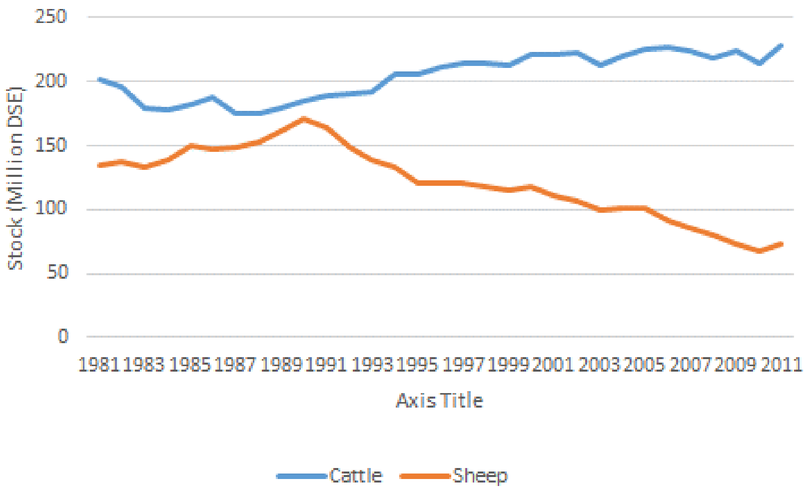


Figure 26 - National sheep and cattle stock numbers for the period 1981 to 2010 (FAOSTAT accessed 3rd Nov 2013) expressed as DSE (using an average value for 400kg cattle of 8 DSE).

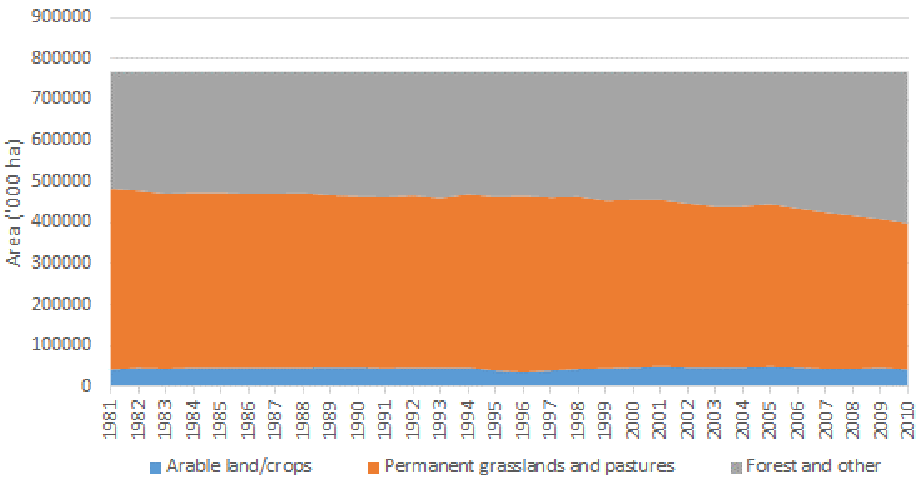


Figure 27 - Disaggregating Australia's total land area of 768 M ha to the main land uses relevant to agricultural production.

Land use for feed production for grain fed cattle was also estimated from national scale statistics as described above.

3 Methodology

This study applied a life cycle assessment approach to quantify the change in greenhouse gas, energy and water use from beef cattle production in Australia for the period 1981 to 2011. A semi-quantitative approach based on best available data was used to estimate the land use change contribution to greenhouse gas emissions and the land use impact category for beef cattle production. Because attribution of land clearing and land use to beef cattle or sheep over the study period was not possible, the results of the trends analysis are considered indicative only.

3.1 Functional unit and system boundaries

The system incorporated the national beef herd producing cattle processed in Australia, and specifically excluded beef from dairy cattle, and beef from herds supplying the live export market. Beef from the dairy herd in Australia contributes an estimated 8-12% to total beef production, based on the analysis of herd numbers and processing statistics in the present study. The study excluded live export animals and the herd supporting these. Australia exports beef from the northern production regions primarily to Indonesia, where these cattle are finished in feedlots and processed for the domestic Indonesian market. While this market is highly relevant to Australia, collecting inventory data for the transport and finishing of these cattle in Indonesia was beyond the scope of the present study.

The study focused only on the primary production system (i.e. cradle to farm gate) using a functional unit of 'one kilogram of live weight' on-farm, immediately prior to processing. The choice of live weight as a functional unit aligns with the system boundary (at the farm gate) and was aligned with the focus of the study, which as at the primary production level. It should be noted that impacts reported post processing will increase, after the loss of mass associated with processing is taken into account. However, a detailed methodological approach is required at this point to handle co-products such as hides, pet food, meat meal and tallow which all arise from the processing of beef. Additionally, the impacts from meat processing would need to be taken into account and this was beyond the scope of the project.

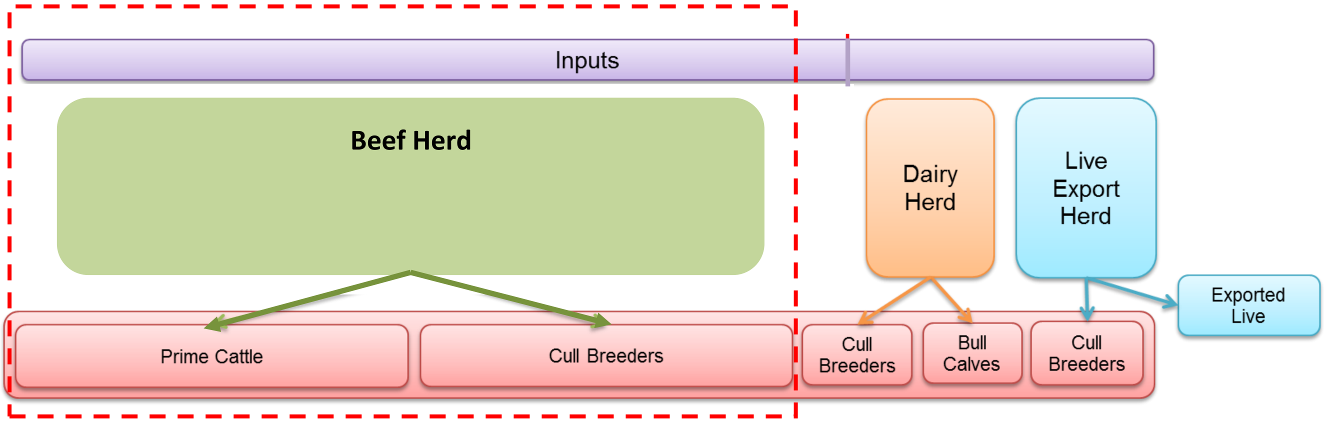


Figure 28 – System Boundary Diagram

3.2 Impact categories

The study included investigation of GHG, energy demand, consumptive water use and land use. The GHG assessment applied IPCC AR4 GWPs of 25 for methane and 298 for nitrous oxide and included an assessment of land use change GHG emissions. Energy demand was assessed using the fossil fuel energy method (Frischknecht et al. 2007) and is reported in MJ of oil-equivalents (LHV). Water use was assessed using the consumptive fresh water use indicator (Bayart et al. 2010) and impact assessment methods were not applied. Land use and land use change (LUC) greenhouse gas emissions were assessed from a broad analysis of national statistics.

3.3 Inventory methods

3.3.1 Herd modelling and prediction of feed intake

A spatially defined national herd inventory was developed from national statistics of livestock numbers, national statistics for cattle processed (ABS 2013b) and the annual ABARES survey (ABARES 2013) for livestock productivity parameters. The herd was modelled in five year periods, ending in the middle of each year (June 30) which matched the dataset provided by ABARES. Consequently, the two five year periods 'share' half of the transitional year. No datasets were identified that explicitly reported the age of young cattle prior to processing. National processing records accessed from the ABS (ABS 2013b) provided accurate weights for males and females processed over the whole analysis period. However, age at processing was required to determine ADG, a critical component of herd productivity. The age of the herd was determined by determined by constructing a national herd production model based on weaning, mortality and cattle sales, and calibrating this model against the national beef herd inventory data reported by the ABS (ABS 2013b). These two datasets enabled a prediction of the mean age of cows, steers and heifers. The predicted age at processing of steers and surplus heifers was verified by comparison to market requirements for age (as indicated by dentition) and weight. The methods and definitions reported in these datasets are explained in the explanatory report by ABARES (2011b). Details of the survey parameters used for this study are reported in Table 6 in Appendix 1. The productivity data are summarised in Table 4. Feed intake (DMI) was estimated using Minson & McDonald (1987) which is the feed intake model used in the Australian National Greenhouse Gas Inventory (NGGI) and relied on productivity data, as reported in Table 4.

Table 4 – Herd production parameters for the five year intervals from 1981-2011

Production parameter	**Units**	1981-1986	1986-1991	1991-1996	1996-2001	2001-2006	2006-2011
Joined females	No.	7,806,726	7,785,274	8,945,291	8,486,621	9,247,685	9,217,722
Unjoined females	No.	1,552,465	1,513,321	1,575,859	1,563,842	1,568,719	1,522,643
Bulls	No.	312,269	311,411	357,812	339,465	369,907	368,709
Steers > 1 year	No.	4,006,410	3,962,470	4,281,868	4,182,244	4,139,809	4,053,108
Calves branded	No.	5,994,399	6,058,721	6,632,298	6,727,739	7,145,714	7,160,021
Weaning per cent	%	76.8%	77.8%	74.1%	79.3%	77.3%	77.7%
Mortality rate	%	4.0%	3.1%	3.0%	2.5%	2.7%	2.7%
Average age of steers at turnoff	years	2.41	2.36	2.34	2.28	2.20	2.18
Average live weight of steers at turnoff	kg LW	474	540	538	586	597	574
Average daily gain of steers - birth to turnoff	kg / d	0.39	0.55	0.55	0.68	0.76	0.72
Average age of surplus heifers at turnoff	years	2.04	1.96	1.96	1.86	1.83	1.81
Average live weight of surplus heifers at turnoff	kg LW	405	438	440	453	426	414
average daily gain of surplus heifers at turnoff	kg / d	0.36	0.50	0.49	0.61	0.52	0.49

3.3.2 Greenhouse gas emissions

Enteric methane from cattle grazed at pasture was modelled using three methods depending on the region or feeding system. Enteric methane from southern regions was modelled using Blaxter and Clapperton (1965), which is based on feed intake and pasture digestibility. To improve the consistency with the NGGI, we applied the same digestibility characteristics as used for the NGGI, for the southern regions. In the northern regions, we applied the prediction equation of Kennedy & Charmley (2012) which is based on feed intake only. Emissions from feedlot cattle were estimated using Moe & Tyrell (1979) as used in the NGGI. These methods are explained in more detail in Appendix 4.

Emissions from manure were predicted using methods consistent with the NGGI for grazing cattle, and included both direct (N_2O and CH_4) and indirect emissions from ammonia volatilisation, leaching and runoff (where applicable). Manure emissions were modelled using a mass balance approach and emission factors from recent Australian research as reviewed by Watts et al. (2012). All methods associated with prediction of manure emissions are provided in Appendix 4. Emissions from nitrogen fertiliser use, which in Australia is primarily associated with the production of feed grain, was determined using the NGGI emission factors and grain production processes previously reported by Wiedemann & McGahan (2011). Emissions from fossil fuel combustion were determined from the energy demand inventory.

3.3.3 Land use change GHG emissions

In LCA studies, the greenhouse gas emissions associated with direct land use change or land transformation are included in the total GHG emissions but are more commonly reported separately, reflecting the higher uncertainty in this contribution and also the fact that it can be a contentious issue. This protocol was followed in the present study. Some methodological issues remain unresolved, despite moves towards harmonisation in carbon footprint methodologies such as ISO TS 14067 and PAS 2050:2011.

The major sources of direct LUC (dLUC) emissions for beef production: (1) clearing of trees for pasture production; and (2) soil carbon loss due to cultivation for feed grain or fodder production (Dalal & Chan 2001) were calculated using methods consistent with ISO TS 14067, using assumptions consistent with Australian GHG inventory reporting where available. Data for dLUC have a higher uncertainty than for other GHG sources for beef production because of the coarser spatial scale and difficulty in attribution of clearing for grazing to beef cattle or sheep.

3.3.4 Energy demand

Energy demand was modelled from farm input data (i.e. farm fuel use, feed inputs, fertiliser, services, transport) which were collated from ABARES (2013). These data were cross checked with case study farm data from different regions of Australia previously modelled by the authors (Wiedemann et al. 2013a, Wiedemann et al. 2013b).

3.3.5 Consumptive water use

The water use assessment used an inventory of consumptive fresh water uses after Bayart et al. (2010), covering all sources and losses associated with beef production both in foreground and background systems. Degradative water use was not included in the assessment and impact assessment was not included. Primary sources of consumptive fresh water use in for beef cattle production arise from livestock drinking requirements and irrigation water used to grow feed fed either directly or indirectly to cattle. While irrigation water data were available on a national scale to inform the analysis, there is no equivalent dataset reporting drinking water for livestock and these were modelled based on herd data. Estimation methods and data sources are explained in the following sections and in greater detail in Appendix 3.

3.3.5.1 Drinking water

Drinking water for grazing cattle was predicted from the livestock inventory by region, using a prediction equation derived from CSIRO (2007) by Ridoutt et al. (2011). This equation is based on live weight, feed intake, moisture content of feed and ambient temperature. Drinking water requirements for feedlot cattle were determined from feed intake and ambient temperature using Winchester & Morris (1956), which was found to correspond well with measured feedlot drinking water data from a range of Australian feedlots reported by Davis et al. (2009).

3.3.5.2 Drinking water supply losses

Appreciable losses may also arise from the water supply system (Wiedemann et al. 2013a, Wiedemann et al. 2013b). This is highly dependent on the water supply system. No definitive dataset was available reporting the proportion of drinking water supplied from different sources (bore, creek/river, dams) across the major grazing regions in Australia. In the absence of these data a survey was conducted of industry experts across all regions (see Appendix 3). Loss rates were determined for different sources, with the highest losses arising from uncapped bores which flow freely to open, unlined drains. Losses from evaporation off farm dams were also accounted for (see Appendix 3).

3.3.5.3 Irrigation

Irrigation water use was determined using data from ABARES (area of land irrigated on beef farms) and two national datasets collated by the Australian Bureau of Statistics (ABS); the “Water Account Australia” and “Water use on Australian Farms”. The latter provided national data for irrigated pasture used for beef cattle, though these data required disaggregation for years prior to 2006. These reports also supplied data for irrigation use in growing feed inputs (hay, grain and supplements).

3.3.5.4 Irrigation water supply losses

From the Water Account Australia reports (1993-94-2009-10 ABS 2000, 2012), irrigation water supply was from the following sources; 46% from distributed sources, 27% from bores and 24% from other surface water sources. The remaining 3% was reuse water from other industries. Four years of data (from 2004-05 to 2010) were available from the national water account where supply losses from distributed irrigation sources were specified. The average loss rate for these four years was 27.1% of total water extracted from the environment (ABS 2006a, 2012). These losses correspond to evaporation losses from state owned supply dams, and seepage losses from irrigation channels. Losses from surface water sources (i.e. direct extraction from unregulated creeks and rivers) and bores were assumed to be negligible.

3.3.6 Land Use

Land use for beef cattle production was analysed from statistics from ABS and FAO. The best available data were for non-arable grazing land but these statistics did not disaggregate land used for beef production from that for sheep grazing. Net Primary Productivity (NPP) was evaluated using simulated estimates on a 5 km grid nationally as a means of categorising land according to its 'quality' with the objective of providing a more accurate assessment of the impact of land occupation for beef production than simply the total number of hectares used for grazing and feed production. Further details are provided in Appendix 5. The total land utilised for cropping in major grain producing regions across the 30 year time period of analysis provided an estimate of land conversion to cultivated grain production based on grain and concentrate use in the herd (including feedlots).

3.4 Handling co-production

3.4.1 Dividing production systems

We handled co-production of beef, sheep and cereal grain within the ABARES dataset by dividing inputs on the basis of land utilised. To divide between sheep and cattle, predicted feed consumption was used as a measure of land utilisation.

3.4.2 Co-production in the beef system

The functional unit of the study did not differentiate between beef from different animal classes and the system boundary stopped prior to meat processing. Consequently, there were no allocation processes required within the beef herd. Manure nutrients from the feedlot sector were handled using a system expansion process to include the avoided production and application of synthetic fertilisers for cropping systems.

3.5 Background data

Background data for upstream processes such as generation and supply of energy and purchased products such as fertiliser were sourced from the Australian LCI database (Life Cycle Strategies 2007). Energy demand associated with the manufacture of purchased inputs such as fertiliser was modelled from either the Australian LCI database (Life Cycle Strategies 2007) where available, or the European EcoInvent (2.0) database (Frischknecht et al. 2005). Feed grain data were based on Wiedemann et al. (2010a) and Wiedemann & McGahan (2011).

3.6 Data limitations

The study relied on data from a number of disparate and discontinuous datasets to construct the herd model, from which predictions of GHG and water use were made. A degree of caution should be applied in interpreting these results consequently. The process of calibrating the model with national slaughter statistics (the most reliable dataset available) ensured that productivity was not grossly over predicted. However, no definitive statistics are collected in Australia on growth rates in slaughter cattle (particularly grass fed slaughter cattle), and consequently there is a degree of uncertainty in the estimates provided here.

A higher degree of caution is recommended for the land use and land use change results presented in the study. Considerable time and effort were spent trying to source spatial data that would allow calculation of land conversion for beef production in Australia by ANRA region over the study period of 1980 to 2010. These evaluations of data indicated that calculations would have such a high uncertainty that combining them in an analysis with other impact categories would significantly decrease the confidence in all results. Therefore the most defensible option for LUC was to present the results of a semi-quantitative analysis separately as indicative of the trend in the greenhouse gas emissions (global warming impact) of beef production in Australia. This is predominantly for the period since 1990 since few data to support robust analysis were available for the 1980s before Kyoto Protocol reporting increased data acquisition. There is a dearth of data on land use for beef cattle in a spatially and temporally disaggregated format as required to undertake a full analysis. In particular because land has moved from sheep to cattle production and between grazing and broadacre cropping over the period of analysis and there were no data that allow tracking of parcels of land between uses assumptions were necessary to estimate the change in land use for beef production. In reviewing those statistics on land use and intensity of production across Australia it was found that different sources provided contradictory data with no real way of determining which values were more likely to be accurate.

4 Results

4.1 Greenhouse gas emissions (excluding Land Use Change)

Greenhouse gas emissions (excluding LUC) rose 19% over the 30 year time period from 1981 to 2011 from 35.8 Gg to 45.1 Gg CO_2-e, reflecting a gradual increase in herd numbers over that time. Over the same time period, GHG intensity declined 14% from 15.3 to 13.1 kg CO_2-e / kg LW, with the improvements coming in the period from 1981-2001 (see Figure 29).

There were a number of drivers influencing emissions intensity over this time period. Between 1981 and 2011 the number of cattle finished on grain rose from an estimated 340,000 head (annual average for 1981-1986) to 2.37 M head (annual average for 2006-2011). Larger numbers of grain finished cattle resulted in higher lifetime ADG for the slaughter herd and reduced the average age at slaughter for young cattle. Reduced emissions primarily come from lower enteric methane as a result of i) reduced maintenance energy and methane production from the slaughter cattle, and ii) reduced daily enteric methane emissions during the grain finishing phase as a result of the high starch diet. The national average age of finished steers decreased from 2.41 to 2.18 years over the time period, while finished weight increased from 474 to 574 kg. The change in slaughter weight was less pronounced for surplus females. Overall, average carcase weights increased by 13.5%, which is reflected in the ABS published slaughter data for Australia over this time period. Mortality rates declined from 4.0% to 2.7%, resulting in higher turnoff. The change was greatest in the northern regions, which may be the result of a transition from *Bos taurus* to *Bos indicus* genetics. Over the investigation period, weaning percentages varied little from the 30 year average (77.2%) and no trend was evident across the analysis period. The lack of improvement in breeding efficiency was a limitation to improvements in herd efficiency and reductions in GHG. Breeding efficiency was higher for the southern regions (aggregated av. of 84% over 30 yrs for southern high rainfall, temperate and pastoral) compared to the northern regions (aggregated av. of 65% for the northern high rainfall, north central pastoral and northern pastoral). These data suggest that there is scope for improvements in breeding efficiency to underpin further reductions in GHG intensity.

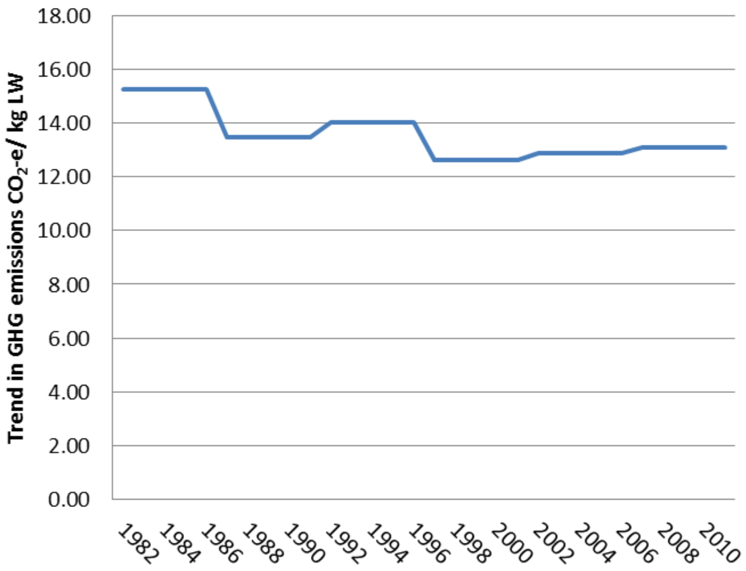


Figure 29 – Change in GHG emissions per kilogram of live weight from the Australian beef herd from 1981-2011

The reduction in emissions intensity was achieved in the 20 years from 1980-2001. This corresponded to a number of productivity improvements; lower mortality rates, higher growth rates in young cattle (grain and grass finished cattle) and heavier carcass weights. One indicator of the improvement in productivity over this period was the increase in beef turnoff per breeding cow joined, which rose 32% from 301 to 396 kg. The greatest changes in productivity resulted from changes in the growth rate and slaughter weight of young cattle, which had the effect of improving efficiency of the whole herd when presented per kilogram of beef finished (Figure 30).

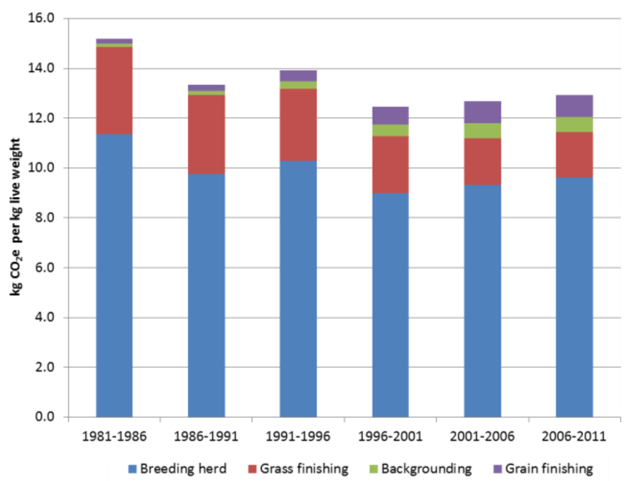


Figure 30 – Change in GHG emissions from different sectors of the beef herd over the period 1981-2011

In the later 10 years (2001-2006 and 2006-2011) the number of cattle finished on grain increased further (1.74-2.37 M head) but this largely corresponded to an increase in the number of cattle turned off across the herd, rather than a shift from grass to grain finishing (Figure 31). This limited the mitigation effect of shifting grass finished cattle onto grain.

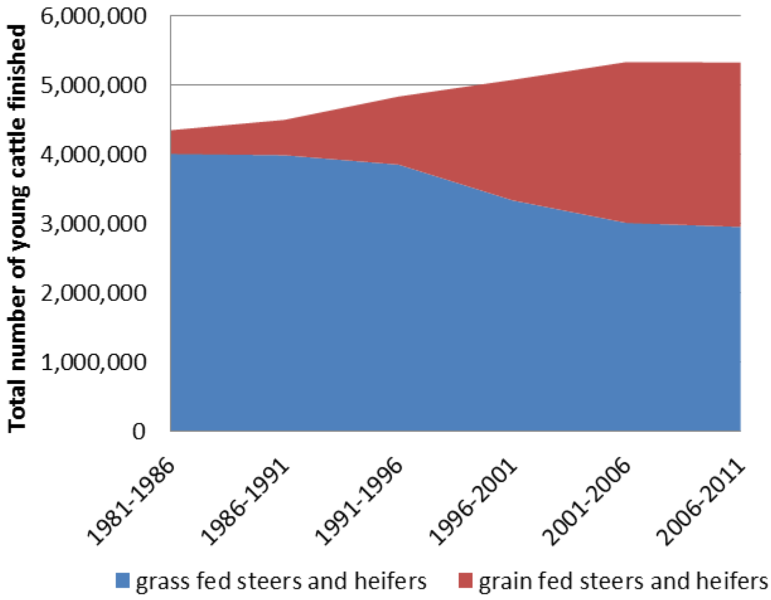


Figure 31 – Change in proportion of young cattle finished on grass and grain between 1981-2011

During the 10 years from 2001-2011 slaughter weights declined slightly across the herd, which may have been in response to drought conditions experienced in many parts of Australia over this decade. Consequently, beef turnoff per breeding cow joined declined slightly, resulting in slightly higher herd emissions. These trends can partly be explained by the long drought periods in the period 2000-2009 in many regions, which suppressed growth rates of livestock on pasture and increased the need for purchased feed inputs. Over this time period, energy use increased markedly, largely as a result of greater feed grain purchases. The higher energy use corresponded with an increase in GHG emissions, partly offsetting the efficiency gains contributed by the larger number of grain fed cattle.

The GHG profile was dominated by enteric methane (88-84%) followed by nitrous oxide (10-11%) and carbon dioxide from fossil fuels (3-5%). Contributions from carbon dioxide increased over the time period with the greater use of fossil fuels, while enteric emissions declined proportionally. The emissions intensity results presented here were similar to case study data presented by various authors for Australian beef production. Australian beef production case studies have been reported by Peters et al. (2010), Eady et al. (2011), Ridoutt et al. (2012) and Wiedemann et al. (2013a, 2013b). These studies have focussed on a limited number of farms, generally over one-three years. Greenhouse gas intensity from these studies varied from 11-20.4 kg CO_2-e / kg LW. The higher results were from Eady et al. (2011) for a study of grass-fed weaner steers from Queensland. Wiedemann et al. (2013b) reported lower values for Queensland beef production of 11.2-12.9 kg CO_2-e / kg LW for grain finished and grass finished cattle respectively using the same methane prediction equation applied in the present study.

Enteric methane emissions averaged 17% lower than the Australian NGGI for the analysis period. While it was not possible to compare every aspect of the modelling with the national inventory, there were some notable differences. Firstly, our study excluded the breeding herd and young cattle associated with the live export trade which are included in the national inventory resulting in lower emissions reported here. Secondly, the present study applied an alternate enteric methane prediction equation for cattle grazing tropical pastures (Kennedy & Charmley 2012) which resulted in 30% reduction in predicted enteric methane from cattle in Queensland, the Northern Territory and northern Western Australia. This prediction equation is based on a larger dataset covering more feed types typical of tropical grazing systems in Australia than the equation used by the NGGI and is considered more robust.

4.2 Consumptive fresh water use

Consumptive fresh water use declined in both absolute terms and as a proportion of production over the investigation period. Average consumptive water use for the five years to 1986 was estimated to be 3442 GL, declining to 1773 GL for the average of five years to 2011. Over this period, water use per kilogram of LW declined from 1465 to 515 L / kg LW (see Figure 32). The three largest contributions to water use were drinking water, drinking water supply losses and irrigation water for pasture. Drinking water supply losses declined from 530 to 190 L / kg LW over the analysis period, with the savings mainly related to lower supply losses from bores. The decline in irrigation water was even more pronounced, from 798 to 152 L / kg LW.

During the investigation period, the Australian Government and land owners have invested in a scheme to cap free flowing artesian bores (DERM 2011), resulting in significant water savings. The second significant change in water use was the decline in irrigation water use for grazing, predominantly in southern regions. In absolute terms, we estimated a decline in irrigation water use for pasture of 1351 GL, or 646 L / kg LW for the whole Australian herd. The decline in irrigation water use corresponds with data published by the ABS, and follows a shift in water use from lower value users (such as beef cattle production) to higher value users under the influence of market pressures for land and water.

The average consumptive water use results for the past five years were higher than reported by Ridoutt et al. (2011) or Peters et al. (2010). These studies investigated either theoretical beef production systems (in the case of Ridoutt) or a very limited number of supply chains (Peters) with different water inventory methodologies and definitions to the present study. Our results suggest irrigation still contributes a large amount of water to the whole industry and this may not have been adequately reflected in previous case study results. Additionally, we have included water supply losses from dams and bores in the present study which are higher than previously suggested.

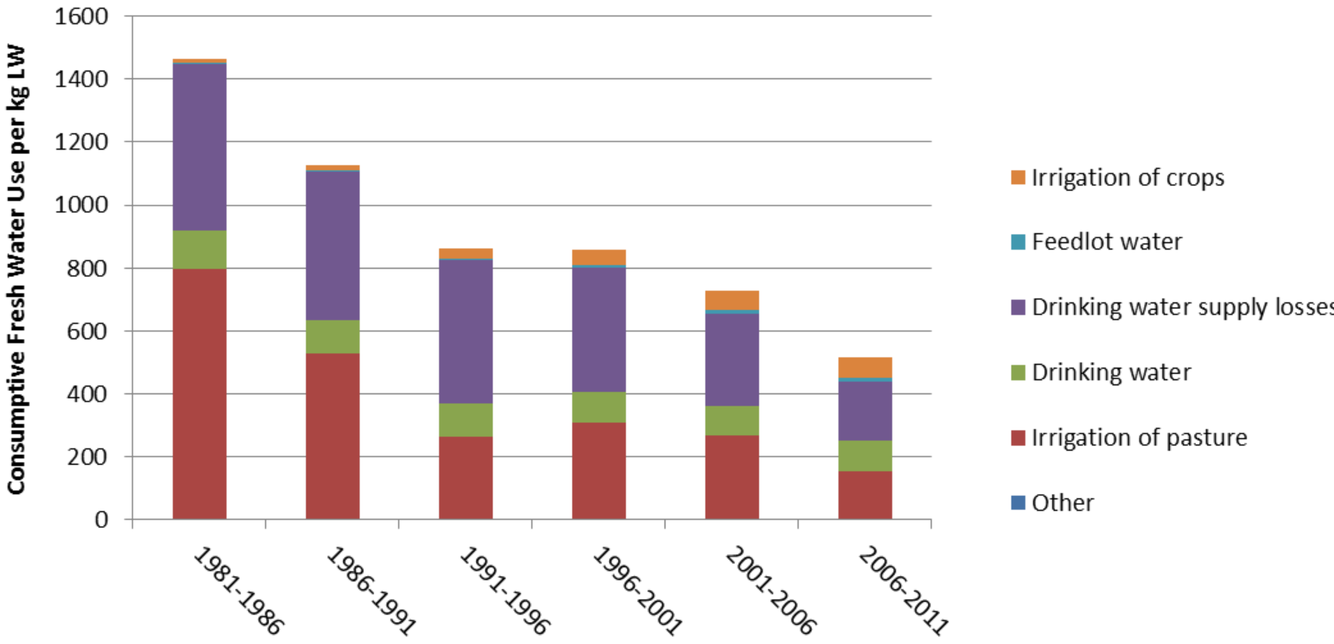


Figure 32 – Change in consumptive fresh water use per kilogram of live weight from the Australian beef herd from 1981-2011

4.3 Energy demand

In contrast to GHG and water use, energy demand increased considerably over the analysis period, from 6.3 to 11.7 MJ / kg LW (Figure 33) before declining slightly in the last period to 11 MJ / kg LW. The large increase in energy demand was primarily associated with feedlot production and to a lesser extent increased energy demand on grazing farms. Smaller increases were also observed in farm fuel use and farm services, which included inputs such as fertiliser use for pastures. The decline in energy use in the last five year period was partly in response to a decline in fertiliser use in this period.

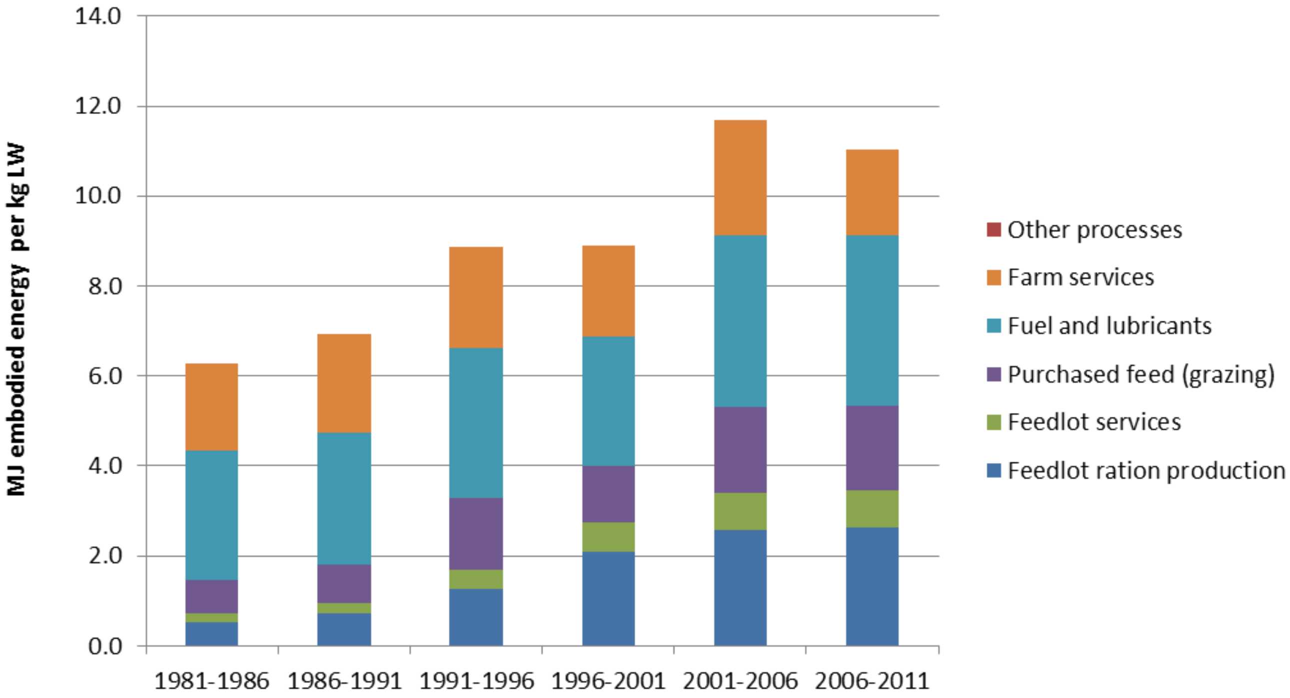


Figure 33 – Change in energy use per kilogram of live weight from the Australian beef herd from 1981-2011

Fewer studies were available to compare energy demand. Wiedemann et al. (*in preparation*) reported energy demand ranging from 3.9 – 14.4 MJ / kg LW for grass finished beef and from 7.8 – 16.5 MJ / kg LW for grain finished beef. The industry average data suggest impacts across the whole herd are towards the upper end of the range found from case studies.

4.4 Land use change greenhouse gas emissions

Deforestation: Analysis of LUC used State level data because spatial data were not was not available for the time period of analysis to enable disaggregation by ANRA region. The majority of LUC in Australia since 1980 has been for agriculture, predominantly for grazing in northern Australia. Land clearing in the wetter and more productive biogeographic regions in the south and along the coast had occurred earlier to provide land for cultivation or intensive livestock production. The total rate of clearing of forests and woodlands has declined over the analysis period with large reductions in Queensland and New South Wales, with a major driver for reductions being regulations restricting broadscale clearing. In Queensland, annual rates of deforestation continued at an annual rate of over 250,000 ha/year until 2006 when legislation to came into effect (AGO 1998, DCCEE 2012). More than 90% of clearing in Queensland each year since 1990 has been for grazing (SLATS 2012). While earlier, clearing in some more arid areas provided land for broadscale cropping, in the inland and in the northern savannahs, thinning or re-clearing has been to improve growth of native and naturalised grasses for grazing including ongoing control of woody regrowth and vegetation thickening.

Attribution of LUC to specific agricultural commodities is necessary to allocate GHG emissions to products e.g. beef, but this can be highly uncertain due to changes in management over the 20 year period over which emissions are assumed to occur (e.g. PAS 2050:2011). It relies on data on land cover post-clearing and statistics on production. More reliable data are available since 1990 due to GHG inventory reporting to the UNFCCC, e.g. on 'Forest conversion to Grassland', and SLATS (2012) reports on Queensland clearing according to subsequent land cover e.g. pasture. Estimates of the proportion of total clearing from 1981 to 1990 for grazing was based on estimates from AGO (1998) and Swift & Skjemstad (2002). However, assigning land cleared for pasture to sheep or cattle is highly uncertain. In the absence of spatial and temporal data to allow for attribution between species all clearing for pasture production (Figure 34) was assumed to be for beef. This is considered reasonable for the period after 1990 but likely to be an over-estimate for the 1980s. The error for GHG emissions for beef will be lower than for LUC itself since land moved from sheep to beef with the decline in sheep numbers from 1990. Over the analysis period, 73 – 93% of clearing for grazing has been in Queensland where beef production has expanded.

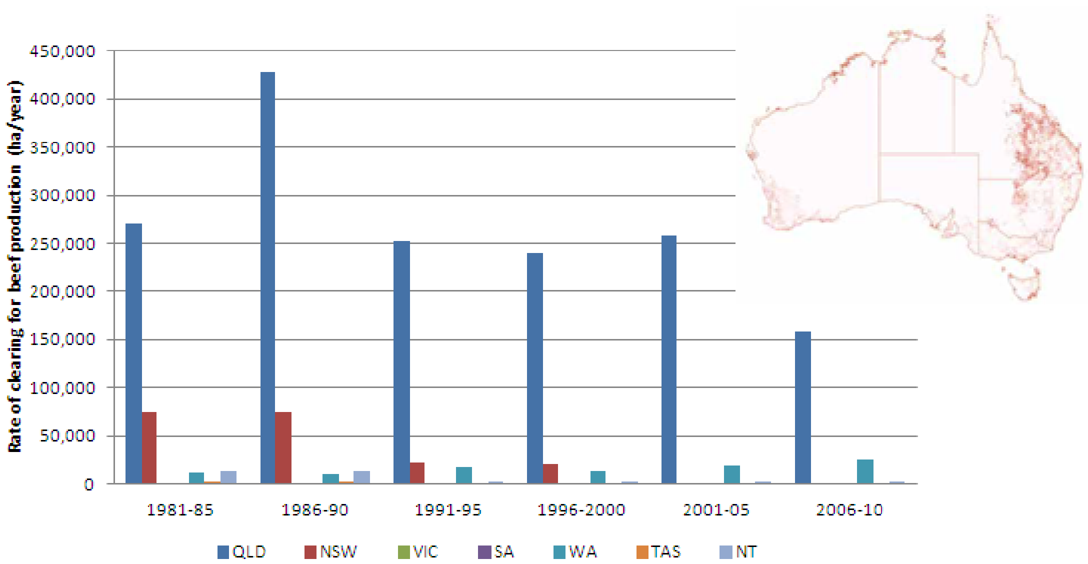


Figure 34 - Annual rate of LUC for beef production in States and Territories of Australia over the past 30 years averaged for 5-year periods from 1980 to 2010. Sources of total clearing data: 1980 to 1990 – AGO (1998); 1990 to 2010 – DCCEE (2012). Insert shows in red the location of clearing events detected between 1990-2011 (DICCSRTE 2013)

LUC GHG emissions 1981-2010: GHG emissions from LUC in Australia have been dominated by continued clearing of woodlands and forest in Queensland over the period since 1990 for which reliable results are available from the national GHG inventory. These calculations use the Tier 3 approach of the National Carbon Accounting System that underpins this sector of Australia's GHG accounts. Using these data and an estimate of the proportion of conversion to grassland in each State that was for beef production from (AGO 1998) combined with 1981-1989, estimates of GHG emissions based on the IPCC 1996 Guidelines as applied in Australia's national reporting prior to development of the NCAS a time series of LUC GHG emissions was developed (Figure 35). The assumptions involved in attribution of clearing for beef production, and in development of datasets together with less precise clearing data for earlier years mean that there is a relatively high uncertainty in these estimates. However the trend is defensible because the major driver, the rate of conversion of forest to grassland is constrained by remotely sensed and internationally reviewed Government data underpinning LULUCF reporting for the Kyoto Protocol. In addition, independently available data from the Queensland Government Statewide Landcover and Trees Study (SLATS) program based on satellite imagery analysis supported by extensive ground-truthing, available for 1990 – 2010, confirm the trend in woody vegetation clearing in Queensland and the dominance of pasture as the replacement land cover category in the state, being 90% or greater of total clearing (Figure 37).

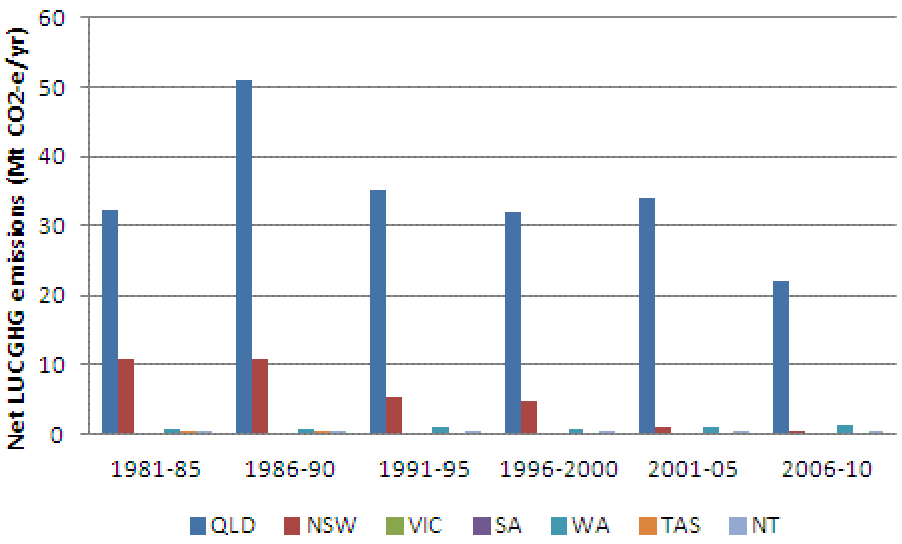


Figure 35 – Estimated greenhouse gas emissions for LUC for beef production based on data for conversion to grasslands (AGO 1998, www.climatechange.gov.au accessed Nov 2013)

Cultivated land use for grain feed, particularly for the feedlot sector, increased more than 7 fold over the analysis period, from 227,818 ha to 1,715,114 ha. Soil carbon losses associated with this increase in land use, were estimated to have increased from 225,540 t CO_2-e/yr in the five years to 1986, to 1,697,963 t CO_2-e/yr in the five years to 2011. This contributed an additional 0.1 to 0.5 kg CO_2-e / kg LW across the whole herd. The possible impact of reduced or no-till on soil carbon emissions has not been included in this analysis because of the uncertainty in impact and rate of introduction relative to land use for feed grain production. Thus the estimated GHG emissions are likely to be an overestimate in regions where no-till has been widely adopted and future research should allow the analysis to be refined.

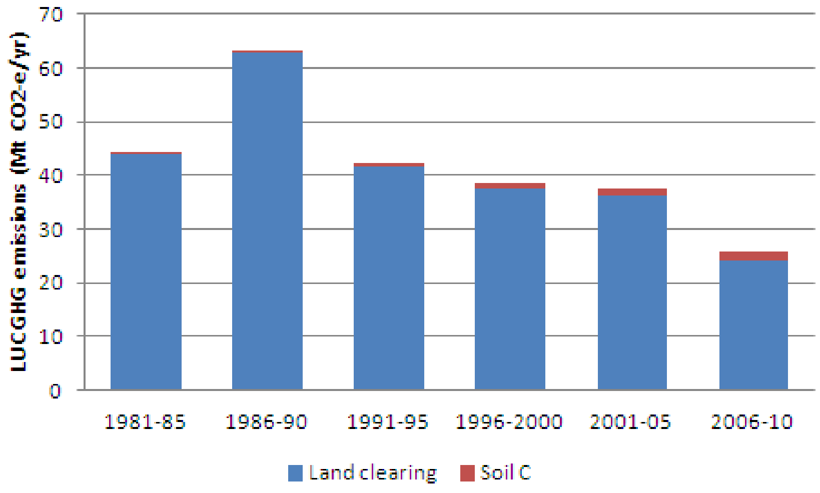


Figure 36 – dLUC Greenhouse gas emissions for beef production

The trend analysis indicates that GHG emissions from deforestation for grazing beef cattle and feed production for grain feeding decreased by 41% over the 30 year analysis period. A significant source of uncertainty in the estimates of trends in GHG emissions is the lack of time series data on movement of grazing land between species (sheep and cattle). In LCA studies, it is usual to amortise emissions from direct land use change emissions over a period of 20 years consistent with guidance under IPCC Good Practice Guidance for Land Use Land Use Change and Forestry (PAS 2050, ISO TS 14067). The contribution to beef production of clearing for the expanding sheep flock during the 1980s when land moved from sheep to cattle could not be assessed.

When expressed per head of meat cattle, GHG emissions from LUC per head decreased from 1981 to 2010 but the decline was not consistent due to fluctuations with seasonal conditions and to the impact of regulation of tree clearing.

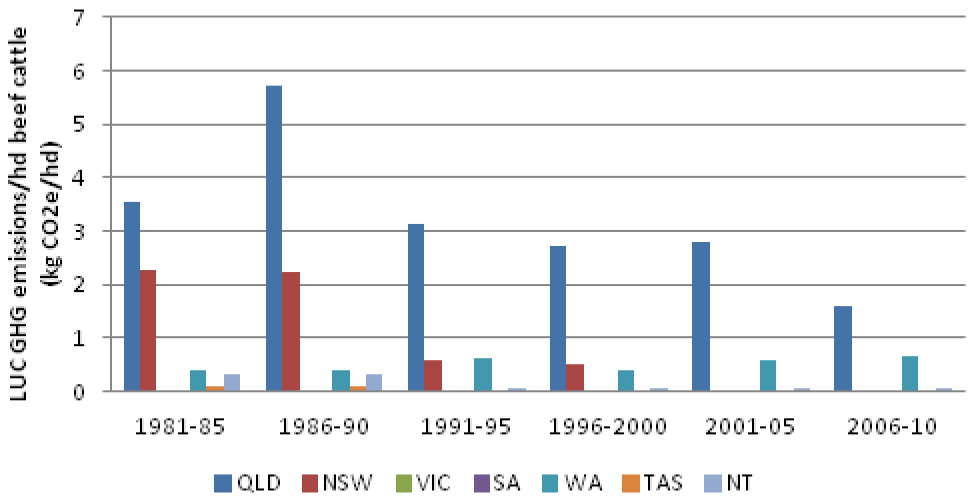


Figure 37 – LUC GHG emissions per head of cattle shows a decline from 1981 to 2010 despite an increase when high rates of clearing occurred in Queensland primarily due to good seasons (data for head of cattle from ABS)

4.5 Land use

The area of land used for grazing has trended downwards over the past two decades (Figure 38) with land classified as non-arable agricultural use dropping from approximately 57% of Australia's total land area (768.23 million ha) in 1981 to 46% in 2010. Land classified as arable or under permanent crops remained almost unchanged at 5.6% with most of the land lost from grazing moving to conservation area and other non-agricultural use.

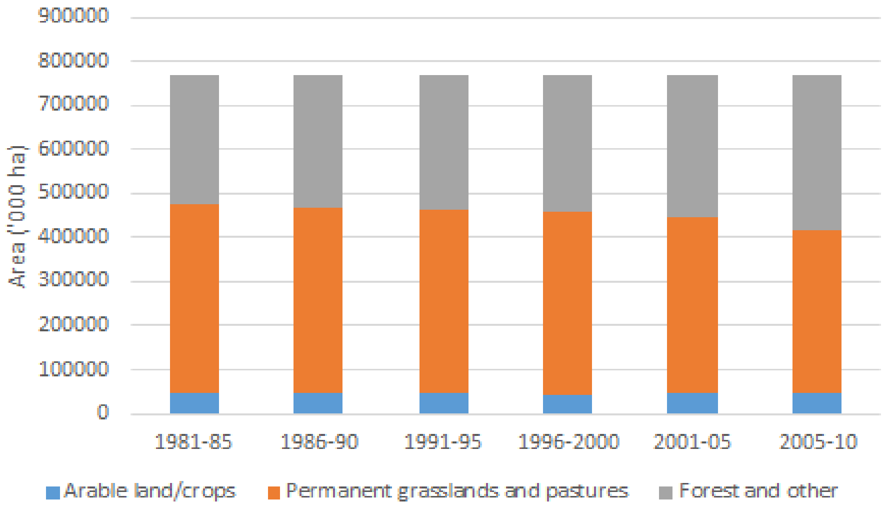


Figure 38 - Trend in the proportion of Australia's land area under arable and non-arable (grazing) agricultural land use over the study period from 1981 to 2010

Reliable data exist on the total grassland and pasture areas used in Australia. The predominant land use is extensive grazing of beef cattle and sheep but the data required to disaggregate land used for the two species were not available. Cattle predominate in northern Australia but sheep and mixed farming systems are important in regions of New South Wales and in southern states. The regions and areas used for grazing sheep have changed over time due largely to decreasing sheep numbers (See Chapter 2.4.2), but other drivers include fluctuations in markets, seasonal conditions and pests and diseases. The area of arable land used directly for beef production also varies and is difficult to quantify but is likely to have changed little over the last 30 years as much of the expansion in the industry has been in the north. Based on yield data for grains and feed grain use by lot feeders the indirect [arable] land use for beef production i.e. arable land used for production of feed was estimated to be 1.2 M ha in 2010. Soil carbon loss associated with feed production on this area was included in the trend analysis for GHG emissions.

ABS data show that the area of non-arable agricultural lands has declined by 19% from 1981 to 2010. However, with sheep numbers declining, neither the magnitude nor direction of change in the area used for beef production can be inferred from the total area of grasslands and pasture. Continued deforestation in Queensland until 2006 and the location of that clearing (Figure 34) is indicative of possible expansion rather than contraction of land use for beef production.

5 Discussion

Australia is a major beef producer with an industry characterised by relatively low input systems utilising extensive rangelands. Productivity tends to be lower than many northern hemisphere countries, and this is largely because of the quality and availability of feed for grazing animals and the frequency of drought years where production is constrained. Australian beef producers operate with a high degree of climatic variability, which has led to low input management systems and a requirement for flexibility. Production varies greatly with climate. In the southern part of the country, the temperate Mediterranean weather patterns have traditionally delivered more reliable rainfall and better feed conditions than in the north. The southern regions are more productive (in terms of weaning rates, growth rates and beef produced per unit area of land), though inputs such as fertiliser are also much higher than in the north.

In the last 40 years, the northern sub-tropical and tropical regions have changed to *Bos indicus* breeds which are favoured for their capacity to handle heat, poor quality feed and parasites. In the extensive north, these breeds have lower mortality rates but also lower weaning rates than *Bos taurus* breeds.

While grass finishing is still the preferred option for many regions, grain finishing has grown in popularity as a means of improving meat quality and improving production in low rainfall years. Grain finishing rose from 8% of the young animal slaughter in the five years to June 1986, to 45% of the young animals slaughtered for the five years to June 2011. This represents the greatest shift in the industry over the analysis period, and is responsible for much of the gain in productivity. Improvements in productivity resulted in a 14% reduction in GHG intensity (excluding dLUC) over the analysis period.

Land use per unit of production appeared to decline by around 19% between over the time period, though further data are required to perform a more definitive analysis. Land use change emissions intensity of beef production declined by approximately 41% over the analysis period. Over the analysis period there was a significant reduction in consumptive water use, largely in response to declines in irrigation water use and improvements in the efficiency of water supply for grazing cattle. These improvements came partly at the expense of greater energy demand from purchased inputs of fuel, fertiliser, feed on grazing farms, and inputs required to grain finish cattle in feedlots.

Three similar studies (Capper 2011, Cederberg et al. 2009, Verge et al. 2008) have been performed investigating the change in emissions intensity over time in other nations. Of these studies, only Verge et al. (2008) determined emissions in five year time steps; while the other studies compared a set year in the past with a more recent year. Capper et al. (2011) compared USA beef production in the year 1977 with 2007 and showed that GHG emissions intensity (excluding dLUC) declined 16.3% over this period. When the values were converted from carcase to live weight using dressing percentages supplied, the change in emissions intensity was 12.6-10.4 kg CO_2-e/kg LW). The reduction in GHG intensity was partly in response to improved productivity in the beef herd for factors similar to our study; increased ADG from birth to slaughter, increased slaughter weights and decreased mortality rates. Additionally, there were improvements in efficiency from a greater proportion of dairy calves entering the beef supply chain. Dairy calves entering the beef production supply chain lower emissions intensity because the GHG impacts from breeding are allocated over the milk and beef produced. We excluded interactions with the dairy herd because this was a smaller and relatively static contributor to Australian beef production, and was beyond the scope of the study. Capper et al. (2011) also reported a 12.1% decline in water use from 1175 to 1019 L for 1977 and 2007 respectively, when converted to a 'per kg LW' basis. It was not clear from the study whether losses from water supply were taken into account. If these losses were not accounted for the results are less comprehensive and therefore not comparable to those presented in this report. Capper et al. (2011) also calculated energy demand, though this appeared to be direct energy demand only, and there was no reference to embedded energy within feed production or farm services. Consequently, the reported values (6.2 and 5.6 MJ / kg LW when converted from BTU) are lower than those reported here, and much lower than values reported for the US LCA study by Pelletier et al. (2010).

Verge et al. (2008) reported a decline in GHG emissions intensity for Canadian beef from 16.4 to 10.4 kg CO_2-e / kg LW (37% reduction) from 1981 to 2001. The decline in emissions was attributed to greater production efficiency, growth in grain feeding and the inclusion of dairy calves in the beef production inventory. The improvement in efficiency (weaning percentages, mortality rates, change in ADG and slaughter weights) were not explicitly reported by these authors.

In contrast to these studies, Cederberg et al. (2009) reported higher emissions for beef production in Sweden in 2005 compared with 1990. This trend was almost entirely driven by less beef production from the dairy herd (which represents over 50% of total cattle in Sweden) and more beef production from specialist beef herds.

Each of these studies identified beef production from the dairy sector as being instrumental to driving changes in the efficiency of beef production (positively or negatively). However, unlike many European countries, Australia's beef output is not heavily influenced by dairy production (the dairy industry contributes <10% of total beef), reducing the capacity of this interaction to influence the efficiency of beef production. Considering the GHG impacts for milk reported by a recent Australian LCA for the dairy sector (Dairy Australia 2012) it is likely that beef from this sector has similar low impacts to other regions of the world and would therefore slightly reduce the overall impacts from Australian beef at least with respect to GHG emissions. The intensity of energy and water use from dairy beef is less clear, and there are no comprehensive Australian LCA research available to quantify these.

6 Conclusions and recommendations

6.1 Conclusions

This study represents the most comprehensive analysis on improvements in the environmental efficiency of Australian beef production on a national scale. These improvements were the result of enhanced herd productivity and changes to management of key resources such as water and land.

Increased herd productivity directly contributed to the 14% reduction in GHG intensity (excluding dLUC) over the 3 decades since 1981. The reduction in emissions was largely in response to the dilution of maintenance feed requirements for the herd, via the following productivity factors i) heavier slaughter weights resulting in greater beef turnoff per breeder animal, ii) improvements in growth rates in grass finished cattle, and iii) greater numbers of cattle being finished on grain. Most of this improvement came in the period from 1981-2001 with little change over the past decade.

The introduction of a major grain feeding industry in Australia has underpinned productivity improvement over the last two decades. While there remains capacity to increase the number of young cattle finished on grain, there are also barriers to this because of the economics of feeding some classes of cattle, particularly in northern Australia. Poor seasonal conditions in the most recent 10 years of the analysis has resulted in poorer feed quality in many beef production regions, with the subsequent effect of poorer productivity across the herd and lack of improvement over this time period. One area where scope may still remain to improve efficiency is by transitioning the domestic market to heavier carcase weights to increase beef turnoff per breeder. There has been a trend underway over several years towards heavier carcase weights in the domestic market and this is expected to continue, bringing with it further productivity gains. The analysis of herd reproductive performance performed in this study showed that there has been effectively no improvement in weaning rate over the past 30 years. Improvement in reproductive performance is a major goal of the beef industry and one worthy of full support not only from the perspective of productivity, but also as a means to lower GHG intensity. While the results of this study cannot be directly compared to those for other national studies due to the differences in impact categories and scope, similar trends are evident to other major beef producing countries such as the USA and Canada. Studies conducted in these countries have shown similar drivers to improving efficiency by increasing slaughter weights (USA) and finishing cattle on grain (Canada).

The increase in supplement and grain use on farms and the increase in feedlot finishing, resulted in an increase in energy use for beef production. In contrast, water use dropped by almost three-fold (1465 to 515 L / kg LW) over the 30 years to 2011. This dramatic reduction in water use was partly the result of competitive demand for irrigation water, resulting in a transfer of irrigation water away from pasture for cattle grazing to higher value industries. The other major factor resulting in declines in water use was the marked improvement in water use efficiency from the Government and Landholder initiative to cap free flowing artesian bores in the rangelands. This study identified major improvements in water use efficiency and reductions in irrigation water use for beef cattle. It is quite likely that constrained water resources will continue to move away from grazing for beef cattle and towards higher value crops, driven by the return on investment for water licences. There is considerable scope for consumptive water use to decline further considering this. However, other factors may counter balance these improvements across the industry. In response to increasingly variable climates, beef producers may need to construct additional, larger farm dams to ensure water supply. Increasing the amount of dam water storage per animal will result in greater evaporation losses.

Land use per unit of production appeared to decline by around 19% between over the time period, though further data are required to perform a more definitive analysis. Land use change emissions intensity of beef production declined by approximately 41% over the analysis period. The significant reduction in land use change emissions in Australia has largely been brought about by a change in Government legislation, and can be considered a permanent shift in policy direction for the country. While retrospective emissions may still be attributed to beef cattle for some years, there is expected to be only modest additional emissions from land use change in the future. This is an important point to be understood in the context of global beef trade. Options to mitigate GHG emissions may exist via strategic tree planting on unproductive lands to sequester carbon, offsetting livestock emissions.

6.2 Data gaps

This study relied on a range of independent datasets, each of which had deficiencies and introduced a degree of uncertainty into the results. The most reliable data collected are from meat processing plants, which provides the total number of females and males killed, and the average carcase weights. These numbers were modified to remove the predicted number of cattle from the dairy industry based on dairy industry statistics, and were also modified to remove the livestock from the live export breeder herd in northern Australia. These provided the best check against total herd productivity over the 30 years. Herd numbers were derived from ABS data, while some herd characteristics such as weaning rates and death rates were taken from the annual ABARES survey data. No dataset provided age of cattle at slaughter, though the ABS provided total numbers of males and females within certain age brackets, which provided some guidance on the age structure of the herd. The age structure for the slaughter herd was cross checked against market specifications to avoid gross errors in the predicted age of slaughter cattle. However, it would be beneficial for future surveys to collect basic age data at the point of slaughter (dentition, ossification) and from farm surveys to improve these predictions.

The ABARES dataset was used to provide data on farm services, which have a large bearing on the energy use results. For mixed farming regions these data were divided into separate farming systems (cropping, sheep, beef) based on the land area and total stocking rate provided in the ABARES dataset. These estimates would be greatly improved if the ABARES survey provided an indication of the level of inputs for cropping (particularly diesel use and fertiliser) and grazing separately.

Fewer data were available to inform the prediction of water use. We predicted drinking water requirements from the livestock inventory, but there were no ready sources of information to determine the source of drinking water for the different regions of the country. We addressed this by contacting industry experts across the country, but there still remains a high degree of uncertainty in these estimates. Second to this, predicted losses from different sources such as dams and uncapped bores were difficult to predict. Dam evaporation losses were predicted using the method applied by Wiedemann et al. (2013a, 2013b) but a high degree of uncertainty is known to exist depending on the volume to surface ratio of dams. Similarly, few data were available to relate losses from uncapped bores to livestock drinking requirements. This will generate greater uncertainty in results from earlier years. Data gaps associated with water use could be addressed by including the following questions in the annual ABARES survey:

- The proportion of drinking water sourced from dams, creeks/rivers and bores.
- Total number of dams.
- Estimated average volume and depth of dams.

Irrigation water use has been reported in greater detail by the ABS since 2006, and the disaggregated data were used to determine beef cattle specific water use for earlier years, back to 1996. These provided a reliable cross check against predicted irrigation water use from the ABARES dataset, which provided total land areas irrigated across the full 30 year period. Irrigation in the first 15 years of the study period is subject to a greater degree of uncertainty than the latter 15 years, and this should be taken into account when reviewing the results.

6.3 Recommendations

This study is an important analysis of national performance. We recommend that MLA invest in data collection programs to improve the quality of data available for future studies. Greatest attention should be placed on improving the measurement of national herd productivity, water use, land use and land use change. This will underpin future research analysing the impact of improvements in resource use efficiency and climate change mitigation from the beef industry.

Considering the data gaps and limitations noted, we recommend that MLA note the uncertainty in the results and make mention of these limitations when communicating the results of this study.

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Appendix 1

Herd modelling and validation of modelling assumptions

There are no comprehensive data available defining production in the national beef herd. The most comprehensive dataset available is the ABS agricultural survey which is conducted every 5 years and provides (within certain margins of error) a national livestock inventory. The survey does not collect productivity data (birth or weaning rates, mortality rates, growth rates) and therefore only provides a basis for modelling the national herd. As the size of any living population (whether it be human beings, wildlife or domesticated animals) can be determined by 3 distinct drivers – birth rates, death rates and migrations, it is logical therefore that the national beef herd is also defined by the same drivers. Australia is effectively closed to imports of live cattle in any significant number. There are many surveys that provide an indication of weaning rates (births are generally first measured at weaning) for various regions of Australia (i.e. ABARES 2013, Bortolussi et al. 2005, O'Rourke et al. 1995). However, none of these could not be considered reliable or suitable for use across the whole country without verification. O’Rourke et al. (1995) reported a range of 48% to 78% weaning rate for various north Australian land systems; Bortolussi et al. (2005) reported mean branding (weaning) rates over a five year running average ranging from 63% to 78% in north Australian herds which was up to 15% higher than O’Rourke et al. (1995) reported for some regions. Recently, McCosker et al. (2011) reported a weaning rate of 64% from 19 herds in north Australia, derived from data collected as part of the industry funded CashCow project monitoring 75 north Australian breeder herds; however, these herds are selected on their ability to perform pregnancy diagnosis and collect a range of animal and pasture data and may not represent a cross section of herds in northern Australia.

Establishing reliable weaning rates is particularly difficult for northern Australia, because it can be difficult to count all animals annually (100% musters are extremely difficult and expensive to achieve). Consequently, determination of the exact number of breeders present which is required to accurately calculate these rates is often unknown. Weaning rates are often simply calculated on the number of calves weaned divided by the number of breeders mustered. It is also often unclear if a given weaning rate refers to the *annual* productivity of the herd, i.e. whether it takes calving interval into account. With the nutritional conditions experienced in northern Australia, it is difficult to maintain annual calving intervals for *Bos indicus* cattle. Clearly enough, if the average calving interval for a herd is 450-460 days, the long term annual weaning rate will be 25% lower than may be apparent from records.

In addition to the difficulties in obtaining reliable birth rate data, it is also difficult to determine mortality rates in extensive herds. Wicksteed (1985) suggested the only reliable data that can be consistently derived from beef business owners in extensively managed regions are sales records. The second most reliable information is the number of animals branded. His suggestion was that mathematical modelling using this data combined over several years together with an understanding of herd structure and typical selling processes could be used to derive far more realistic estimates of mortality and reproductive rates within herds. Wicksteed used this approach to show that the ratio of females/total sales was an indicator of both mortality and reproductive rates, which tend to be negatively correlated with each other. Jubb & Annand (1996) used a similar approach when estimating deaths in breeder – age female cattle in the Kimberley region of Western Australia. While figures of 3-5% are often reported as the level of breeder cow mortality occurring in northern Australia, estimates of rates greater than 10% as reported by Jubb are difficult to accept by industry. More recently, Henderson et al. (2012) (MLA Final report 2012) attempted to assess breeder cow mortality rates on a herd basis from randomly selected herds in 7 key beef producing regions of northern Australia. While they were frustrated with the quality of data in most instances, they were able to develop a rigorous livestock inventory approach such that deaths and death rates could be calculated over the period 2006 to 2011. The average female mortality rate in the 36 properties selected was found to be 5.64% but one suspects that the death rate in the breeding component of the female herd would be somewhat higher than this figure as these animals are exposed to the additional stresses of pregnancy and lactation.

Similar to the findings of Wicksteed at the farm level, the most reliable national data are those from meat processing and live export records. Hence, we developed our herd modelling with reference to data from the ABS (herd inventory) and ABARES (weaning and mortality rate) but optimised our modelling using processing data. This provided some confidence in the estimates of parameters used in this project at a national level.

As noted by Wicksteed, the number of animals processed and their sex provide important data relating to the weaning rate and mortality rate of the herd. In assessing national mortality rates we made the following assumptions:

- Deaths after weaning in dry cattle (both male and female) are assumed to be relatively low.
- It was assumed that 50% of all cattle born will be male and 50% will be female.
- The percentage of females turned off each year, can therefore provide a relative good indication of the mortality rates in breeding females – all the above points taken into consideration.

Table 5 – Percentage of male and female cattle turned off from the Australian herd for two time periods (1980-84 and 2006-10 – ABS) shows a simple analysis of the change in herd numbers and percentage of females turned off from the herd for two time periods (1980-84 and 2006-2010). The trend line over the 30 year period (Figure 39) shows the gap between male sales and female sales is narrowing and illustrates that substantial efficiency gains have been achieved in reduction of loss of females.

Table 5 –Percentage of male and female cattle turned off from the Australian herd for two time periods (1980-84 and 2006-10 - ABS)

(All numbers x'000)	**1980/84**	**2006/2010**
Starting Numbers	26125	28393
Closing Numbers	22094	26550
Change in herd size over period	4031	1843
Average Male sales	3744.8	4628.0
Average Female sales	3058.3	3960.8
% females turned off	45.0%	46.1%

Note: Sales = cattle slaughtered or exported as recorded by ABS

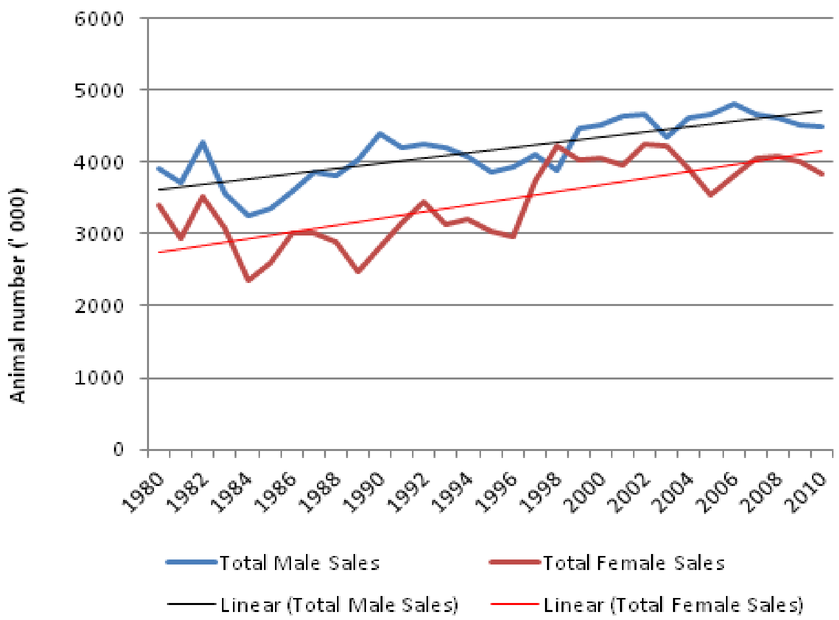

Figure 39 - Trend in turn-off over the 30 year analysis period

While trends in the female proportion of the kill provide insights into mortality rates, the proportion of male cattle processed provides a reasonable validation dataset for modelling weaning rates. It is reasonable to assume a strong positive correlation between the number of male calves weaned and the number of male cattle slaughtered and that the losses between weaning and sale would be reasonably small. The reasons why the death rates in male cattle between weaning and slaughter is low can be listed as follows:

- The male cattle component of the beef herd have traditionally been seen as the most valuable component of the herd and the major focus of turnoff strategies, hence they are managed carefully to minimise mortalities.
- Male cattle are not subjected to nutritional stress that accompanies lactation and pregnancy.
- Male cattle are not subject to fatal diseases of the reproductive tract or complications of the birthing process.
- The national herd is free of most major diseases that cause significant fatality rates and vaccines are available for the known diseases such as the Clostridial disease that can cause economic loss.

By taking the male component of the herd as derived from slaughter and live export data and multiplying it by 2, it was therefore possible to validate the predicted weaning rate for the national herd. While conception failure, abortion and neonatal calf losses all contribute to the reproductive efficiency equation, the annual weaning rate is the ultimate gauge of reproductive efficiency in the national herd. In this way, annual meat processing and live export data (ABS 2013b) provided an independent validation dataset for the full analysis period.

Meat processing data

As noted, accurate meat processing data were a critical validation tool for the herd model. Annual (financial year) red meat slaughter data for each state (number of animals and sex) and tonnes of beef produced were obtained from ABS (2013b). These data was collated for the whole of Australia to give five year average slaughter data for the six time periods. The available data includes all meat produced and required correction to exclude meat produced from the Australian dairy cattle herd. Dairy slaughter numbers and mass were estimated from ABS (2013a). The removal of dairy cattle provided an estimate of slaughter data, both numbers and mass for beef cattle only.

Annual (financial year) red meat slaughter data for each state (number of animals) and tonnes of beef produced were obtained from ABS (2013b). These data was collated for the whole of Australia to give five year average slaughter data for the six time periods. The available data includes all meat produced and required correction to exclude meat produced from the Australian dairy cattle herd. Dairy slaughter numbers and mass were estimated from ABS (2013a). The removal of dairy cattle provided an estimate of slaughter data, both numbers and mass for beef cattle only. Turnoff from the dairy herd is more readily defined based on birth rates and culling rates. Additionally, the total numbers from the dairy herd (see Figure 40) are relatively low and static compared to beef numbers.

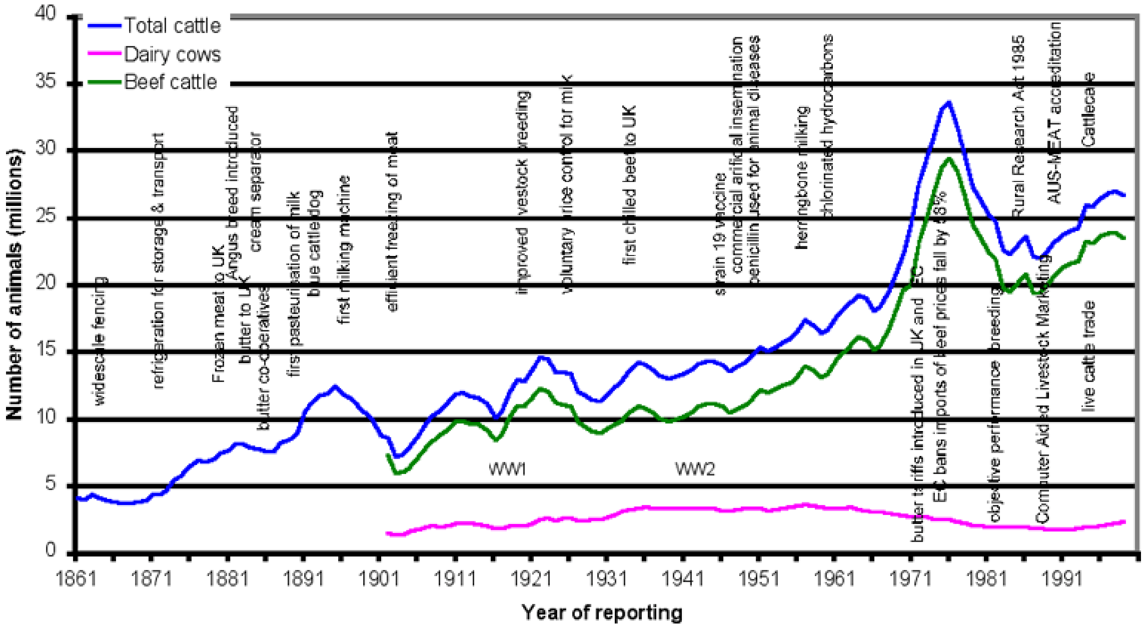

Figure 40 –Australian cattle numbers showing totals from the dairy and beef sectors

Herd modelling

To produce five year average breeder herd numbers, livestock inventory data was obtained from historical total cattle numbers from ABS (2013a), and proportioning these by class (total milk cattle, total meat cattle, meat cattle females > 1yr and meat cattle steers and bullocks > 1 year) based on ABS (2008a, b). Historical calf branding rates and total mortality rates were determined from ABARES (2013). Table 6 shows the data collected by the annual ABARES surveys, which are conducted across the whole country and provided a dataset spanning the whole analysis period. The beef herd was divided into various classes: breeding cows, calves < 1 yr, females > 1 yr (unjoined) and steers > 1yr for the six separate time periods and the seven selected regions. Bull numbers were calculated from a set ratio of 4% of bulls to breeding cows across each region and time period.

The progeny (steers > 1 yr and unjoined females > 1 yr) numbers and their average age were divided into various classes: feedlot finishing, grass-fed backgrounding (for feedlots), live export and grass-fed finishing. The surplus female progeny herd was categorised into both grain fed domestic heifers and grass fed heifers. The steer proportion of the progeny was also divided into both feedlot and grass fed finishing. Three feedlot classes were developed, short-fed (70 days, domestic market), medium fed (110 days, export market) and long fed steers. These two classes were chosen to enable both the variation in feed ration and animal performance to be captured in the modelling. Grass-fed backgrounding steer categories were developed to provide backgrounding steer numbers for the feedlot finishing classes. Live export cattle numbers and weight were determined from ABARES (2013) and ABS (2013b). We removed the live export sector (including the supporting herds) from this analysis in order to focus on beef processed in Australia.

Table 6 –Description of ABARES data collection parameters

Direct data collected	Calculated outputs from data
Cows mated (no.)	Beef turnon rate (%)
Beef bulls at 30 June (no.)	Beef turnoff rate (%)
Beef calves at 30 June (no.)	Cattle death rate (%)
Beef cows at 30 June (no.)	Share of females in beef herd (%)
Beef cattle transferred in (no.)	Beef cattle branding rate (%)
Beef cattle transferred out (no.)	Total Cattle - June 30
Steers and other beef cattle at 30 June (no.)	Total cattle (less calves)
Beef heifers at 30 June (no.)	Cows
Beef cattle at 30 June (no.)	Cows (% of total - less calves)
Beef cattle purchases (no.)	Branding rate (%)
Beef cattle sold (no.)	Calves Branded
Beef cattle turned off (no.)	Calf Weaning rate (%)
Beef cattle turned on (no.)	Proportion grazing land for cattle (%)
Beef cattle sold live export (no.)	Proportion of total land for cattle (%)
Deaths	Land for cattle (ha)
Beef cattle sold ($)	Land area (ha/hd)
Live export cattle sales price per head ($	Land area (ha/hd) - less calves
Cattle sales (incl. live export) price per head ($)	Land area (ha/cow)
Beef cattle purchases ($)	% Cattle sold to live export
% Farm for Grazing - Sheep and Cattle	

Key production parameters to drive the modelling applied to each region.

Feedlot production parameters

The total number of cattle in feedlots was provided from historical industry collated data, with percentage of feedlot classes, entry age, days on feed, entry and exit live weights and male to female proportion provided by industry experts and studies conducted by Davis et al. (2008a, b). Feedlot production characteristics are shown in Table 7 to Table 9.

Table 7 – Production characteristics for domestic feedlot heifers

Production parameter	Units	1986	1991	1996	2001	2006	2011
Entry weight	kg LW	340	350	360	360	360	360
Days on feed	days	70	70	65	65	60	60
ADG at feedlot	kg / d	1.29	1.29	1.38	1.54	1.67	1.67
Exit weight	kg LW	430	440	450	460	460	460
Daily Feed Intake	kg DMI / d	8.7	8.9	9.2	9.6	9.8	9.8
Mortality rate - Northern heifers	%	7.0%	5.0%	5.7%	4.3%	4.3%	4.6%
Mortality rate - Southern heifers	%	3.4%	2.9%	3.0%	2.6%	3.1%	3.1%

Table 8 – Production characteristics for export mid-fed feedlot steers

Production parameter	Units	1986	1991	1996	2001	2006	2011
Entry weight	kg LW	360	360	360	360	370	370
Days on feed	days	140	140	140	140	135	135
ADG at feedlot	kg / d	1.45	1.49	1.51	1.61	1.61	1.64
Exit weight	kg LW	563	568	572	585	588	591
Daily Feed Intake	kg DMI / d	10.1	10.2	10.3	10.6	10.7	10.8
Mortality rate - Northern steers	%	1.8%	1.3%	1.5%	1.1%	1.1%	1.3%
Mortality rate - Southern steers	%	1.1%	1.0%	1.0%	0.9%	1.1%	1.2%

Table 9 –Production characteristics for export long-fed feedlot steers

Production parameter	Units	1986	1991	1996	2001	2006	2011
Entry weight	kg LW	430	430	430	430	430	430
Days on feed	days	245	250	260	270	280	280
ADG at feedlot	kg / d	1.00	1.00	0.98	0.94	0.91	0.91
Exit weight	kg LW	675	680	685	685	685	685
Daily Feed Intake	kg DMI / d	10.3	10.4	10.3	10.3	10.2	10.2
Mortality rate - Northern steers	%	3.2%	2.3%	2.7%	2.2%	2.3%	2.6%
Mortality rate - Southern steers	%	1.9%	1.8%	1.8%	1.7%	2.3%	2.4%

Table 10 –Production characteristics for grass finished steers – northern and southern Australia

Production parameters	Units	1986*	1991	1996	2001	2006	2011
Steers - southern Australia							
ADG (birth to slaughter)	kg / d	0.51	0.61	0.59	0.64	0.70	0.59
Age at slaughter	mths	28	27	28	29	27	27
Exit weight	kg	462	534	536	601	599	517
Steers - northern Australia							
ADG (birth to slaughter)	kg / d	0.44	0.50	0.46	0.53	0.57	0.52
Age at slaughter	mths	33	33	33	32	32	33
Exit weight	kg	462	528	487	547	593	551

* Data represent the average of five years to June 30 in the reported year.

Appendix 2

Farm and feedlot inventory data

Farm inventory data

Farms use a range of inputs including energy for transport and farm operations, inputs for crop and pasture production (fertilisers, chemicals), and inputs associated with livestock (veterinary products, feed). Additionally, farms rely on communications and a number of professional services such as insurance, accounting and banking.

All farm services inventory data used for this study were based on ABARES commodity data (ABARES 2013) described in Section 3.3.1. The farm inputs that were used from the ABARES dataset consisted of administration, fodder, animal health, fertiliser, freight, and fuel and lubricants. These data were originally presented as total dollars per farm. Total product use was determined by dividing categories into a number of products assumed to be used by farms (Table 11) and assigning values based on historical records of purchase input costs. Overhead inputs were divided across different production systems (i.e. beef, sheep and cropping) based on land and feed use for the different enterprises. Where specific inputs were known to be more heavily utilised by one farm enterprise than another, such as the use of diesel, fertiliser and herbicides in mixed livestock and cropping regions, these were modified to reflect expected inputs for cropping based on gross margins such as those available from government agricultural advisory agencies (i.e. NSW DPI 2012).

Table 11 – Assumed component fractions for ABARES farm services data

	Northern Region	**Southern Region**
Fodder Components		
Hay	0.025	0.5
Wheat	0.025	0.3
Supplement	0.95	0.2
Fuel & Lubricant Components		
Diesel	0.90	0.90
Petrol	0.07	0.07
Oil	0.03	0.03
Administration Components		
Electricity	0.75	0.75
Communications	0.21	0.21
Professional services	0.03	0.03
Fertiliser		
Super phosphate	0.85	0.6
Potash	0.1	0.1
Urea	0.05	0.2
Lime	0.05	0.1

Inventory data are reported in dollars of expenditure per tonne of DMI consumed by the herd. One tonne of DMI can be converted to dry sheep equivalents (DSE) by dividing by 2.5, or to adult equivalents (AE) by multiplying by approximately 2.5. Table 12 and Table 14 show the inventory data for the northern and southern regions.

Table 12 – Farm services data for northern region

NHRZ	1986	1991	1996	2001	2006	2011
Administration	0.99	1.39	1.27	1.34	1.31	2.62
Fodder	0.87	1.82	5.57	3.12	7.64	8.00
Beef livestock (drenches, dips, vet supplies)	0.57	0.83	1.03	1.11	1.28	2.25
Freight	0.74	0.96	1.31	1.28	1.99	1.67
Fuel and lubricants	0.81	1.61	1.52	1.94	2.33	2.99
Fertiliser	0.26	0.47	0.90	1.05	1.18	0.72
Total Farm Services ($/t DMI)	4.23	7.08	11.61	9.84	15.74	18.25
NTZ						
Administration	0.93	1.79	2.41	2.15	3.52	3.05
Fodder	0.29	1.32	7.66	3.13	11.30	11.36
Beef livestock (drenches, dips, vet supplies)	0.55	1.02	1.08	1.69	2.47	2.26
Freight	0.73	2.06	2.85	2.92	3.92	3.45
Fuel and lubricants	0.62	1.98	3.76	2.84	5.12	4.87
Fertiliser	0.02	0.16	0.24	0.41	0.69	0.77
Total Farm Services ($/t DMI)	3.13	8.32	18.01	13.14	27.02	25.77
TNPZ						
Administration	0.50	0.57	0.67	0.64	0.70	0.82
Fodder	0.77	0.96	1.12	0.93	1.67	2.39
Beef livestock (drenches, dips, vet supplies)	0.41	0.50	0.56	0.74	1.03	1.19
Freight	1.06	1.01	1.28	1.13	1.14	1.75
Fuel and lubricants	1.56	1.63	1.95	1.85	1.94	2.67
Fertiliser	0.14	0.12	0.17	0.11	0.17	0.07
Total Farm Services ($/t DMI)	4.43	4.78	5.75	5.41	6.64	8.89

Table 13 continued – Farm services data for northern region

NHRZ	1986	1991	1996	2001	2006	2011
CNPZ						
Administration	0.48	0.55	0.58	0.52	0.72	1.22
Fodder	1.07	1.35	1.48	1.17	1.89	2.73
Beef livestock (drenches, dips, vet supplies)	0.36	0.47	0.44	0.54	1.00	1.21
Freight	1.38	1.43	1.72	1.44	2.04	3.45
Fuel and lubricants	1.57	1.81	2.01	2.16	2.91	4.04
Fertiliser	0.01	0.04	0.04	0.01	0.05	0.03
Total Farm Services ($/t DMI)	4.87	5.64	6.26	5.85	8.60	12.68

Table 14 – Farm services data for southern region

SHRZ	**1986**	**1991**	**1996**	**2001**	**2006**	**2011**
Administration	2.20	2.51	2.90	3.33	3.99	3.34
Fodder	0.85	1.21	2.73	4.33	4.85	6.82
Beef livestock (drenches, dips, vet supplies)	1.35	1.72	2.15	2.20	2.93	3.30
Freight	1.35	1.46	1.83	1.77	2.26	2.72
Fuel and lubricants	2.62	3.19	3.32	3.55	4.14	3.90
Fertiliser	2.37	5.79	5.70	6.98	9.56	7.39
Total Farm Services ($/t DMI)	10.73	15.88	18.62	22.17	27.73	27.46
STZ						
Administration	2.26	2.12	2.16	1.83	2.90	3.11
Fodder	1.45	2.10	4.14	3.17	5.90	10.55
Beef livestock (drenches, dips, vet supplies)	1.93	2.17	2.45	2.35	6.90	4.59
Freight	1.63	2.15	2.46	2.36	3.23	4.22
Fuel and lubricants	0.86	1.28	1.66	1.23	1.63	2.45
Fertiliser	1.62	1.38	1.42	1.36	1.19	2.55
Total Farm Services ($/t DMI)	9.75	11.20	14.29	12.31	21.76	27.47
SPZ						
Administration	1.09	2.10	1.68	1.30	2.13	2.42
Fodder	0.33	0.60	0.75	0.56	3.51	1.50
Beef livestock (drenches, dips, vet supplies)	0.47	0.66	0.60	0.72	1.26	1.40
Freight	2.91	2.96	3.87	3.42	3.93	4.50
Fuel and lubricants	2.56	3.58	3.53	2.76	3.68	3.81
Fertiliser	0.01	0.07	0.29	0.20	0.57	0.26
Total Farm Services ($/t DMI)	7.38	9.98	10.72	8.97	15.07	13.88

Feedlot inventory data

Feedlot inventory data were based on data collected from eight feedlots over a two year period from detailed metering and monitoring of energy and commodity use (Davis et al. 2008a, b). The major inputs were diesel, petrol and electricity. A combined domestic/mid-fed feedlot services and a long fed feedlot services inventory were compiled (Table 15).

Table 15 – Material inputs and outputs for feedlots

		Domestic/mid-fed feedlot	Long-fed feedlot
Inputs	**Units**	**(per head day)**	
Energy			
Electricity	kWh	0.056	0.030
Diesel	L	0.014	0.034
Petrol	L	0.003	0.004
Vehicle	km	0.002	0.002
Other inputs and services			
Veterinary services	$	0.148	0.148
Communication services	$	0.003	0.003
Insurance	$	0.002	0.002
Automotive and feedlot infrastructure repairs	$	0.185	0.185
Accounting	$	0.103	0.103
MLA levy	$	0.105	0.105
Horse feed	kg	0.005	0.005
Staff travel	km	0.009	0.009
Freight and cartage excl. livestock	tkm	0.0002	0.0002

7.1.1 Feed milling and rations

Feed milling inventory data for both types of feedlot modelled were based on records kept by the eight feedlots described previously (Davis et al. 2008a, b). These data are presented in Table 16.

Table 16 – Major inputs for feed milling at feedlot

Inputs	Data source description	Units	Per tonne delivered to bunk
Energy			
Electricity	Data collected by feedlot	kWh	6.82
LPG		L	4.08
Butane		L	0.48
Diesel		L	1.13
Water	Data collected by feedlot	L	150.45

Feed inputs are the largest input for feedlot cattle production. Cattle are fed on diets matched to the nutritional requirements of the growing animals. Rations are formulated on a 'least cost' basis, resulting in variations to the input products throughout the year. For the purposes of this study, a combined domestic/mid-fed feedlot ration and a long-fed feedlot ration were developed. Aggregated commodity inputs (aggregated over 12 months) from seven feedlots were used for the domestic/mid-fed ration, while one feedlot was used as the basis for the long-fed feedlot ration. Feed input data were also required for modelling manure GHG emissions (i.e. digestibility, ash and crude protein) and these data were generated based on the specific rations. Commodity inputs to the rations were simplified using a substitution process (Wiedemann & McGahan 2011, Wiedemann et al. 2010b). Table 17 shows the aggregated, simplified rations for the two types of feedlot.

Table 17 – Aggregated, simplified rations for the feedlots

Commodities (protein content in brackets)	Units	Northern domestic/mid-fed feedlot	Southern domestic/mid-fed feedlot	Long-fed feedlot
Barley (10%)	kg as fed	63.5	127.0	40.4
Sorghum (10%)	kg as fed	444.7	190.6	0.0
Maize (8%)	kg as fed	0.0	31.8	35.0
Wheat (13%)	kg as fed	127.0	285.9	458.7
Canola (36%)	kg as fed	10.5	10.5	11.4
White fluffy cottonseed	kg as fed	78.7	78.7	57.6
Hay	kg as fed	32.0	32.0	0.0
Straw	kg as fed	6.7	6.7	132.0
Silage	kg as fed	109.2	109.2	162.2
Cotton Hulls	kg as fed	23.4	23.4	0.0
Canola oil	kg as fed	11.1	11.1	0.0
Molasses	kg as fed	24.4	24.4	79.5
Feed additives	kg as fed	68.7	68.7	23.2
Total	**kg as fed**	**1000.0**	**1000.0**	**1000.0**

Background data sources

All processes that were part of the system boundary, but beyond the farm boundary, were included in the background system. These data were drawn from a number of inventory databases, in particular, the Australian AustLCI database and EcoInvent databases provided the majority of background process data. Upstream data associated with services such as insurance, telephone and veterinary services were based on the ABARES data for the region matched with economic input-output tables from the US economy. Impacts associated with services are typically very small; however this approach provided a comprehensive coverage of these impacts and was therefore included for completeness. No adjustment was made for conversion of Australian dollars to US dollars, as the services were not assumed to be driven by exchange rates.

Appendix 3

Water use inventory

Data collection and modelling approach

The water inventory was developed by using a series of water balances for important processes in the foreground system. Full characterisation of water sources (inputs) and outputs from each stage were determined, including all losses associated with water supply. Consumptive water use data for background processes are not well documented within the AustLCI and EcoInvent databases and as a consequence, all process water in the background system was assumed to be a 'consumptive use'. In practice this is unlikely, but this assumption was conservative, and the error was small because the contribution from background processes was <0.1% of total consumptive water use. Aggregated climate data for each region are presented in Table 18.

Table 18 – Summary of climate data used in water modelling for each region

System	Rainfall (mm / yr)	Pan Evaporation (mm / yr)
Region 1 - NHRZ	805	1889
Region 2 - SHRZ	877	1923
Region 3 - NTZ	636	2451
Region 4 - STZ	627	2057
Region 5 -TNPZ	909	2801
Region 6 - CNPZ	393	3070
Region 7 - SPZ	288	2729

Farm water inventory

Irrigation water

The total area of irrigated land for each region and time period was determined from the ABARES survey data over the 30 year period. This dataset provided total areas of land irrigated on beef farms but not the irrigation rate. Irrigation rate data were available from the ABS for the period 2005-2010, which provided total volumes of irrigation water by region attributable to beef cattle production. This time period was used to determine an average irrigation rate of 2.7 ML/ha. This value was then applied over the 30 year time period in lieu of reported irrigation rates prior to the reported period.

Irrigation water use was highest in the south eastern regions of NSW (Riverina and Central West) and Victoria (Central North).

Farm irrigation water supply balance

Table 19 shows the assumed sources for irrigation water supply, along with the proportion of total water supplied by each, for each breeding region. Table 20 shows the irrigation water supply sources for the grow-out cattle in the northern and southern regions. Losses associated with irrigation water supply were determined from the ABS national water accounts, and amounted to 27.1% of total extraction from the environment for water supplied from irrigation schemes.

Table 19 – Sources of irrigation water supply for breeding farms by region

Drinking water source (%)	1981-86	1986-91	1991-96	1996-01	2001-06	2006-11
NHRZ Region						
Dam	10	10	10	10	10	10
Watercourse	90	90	90	90	90	90
Total (%)	100	100	100	100	100	100
SHRZ Region						
Dam	10	10	10	10	10	10
Watercourse	90	90	90	90	90	90
Total (%)	100	100	100	100	100	100
NTZ Region						
Dam	10	10	10	10	10	10
Watercourse	90	90	90	90	90	90
Total (%)	100	100	100	100	100	100
STZ Region						
Dam	46	46	46	46	46	46
Watercourse	54	54	54	54	54	54
Total (%)	100	100	100	100	100	100

Table 20 – Sources of irrigation water for grow-out cattle for northern and southern regions

Drinking water source (%)	1981-86	1986-91	1991-96	1996-01	2001-06	2006-11
Northern region						
Dam	10	10	10	10	10	10
Watercourse	90	90	90	90	90	90
Total (%)	100	100	100	100	100	100
Southern region						
Dam	23	23	23	23	23	23
Watercourse	77	77	77	77	77	77
Total (%)	100	100	100	100	100	100

Crop irrigation water use

Irrigation water use associated with crop production for grain and other commodities fed to beef cattle were determined from the total feed inputs and commodities (Table 17) and irrigation water use for cereal grains and cotton seed. Irrigation water associated with feed use was predicted from total irrigation volumes for cereal grains reported by the ABS. We did not differentiate between water irrigated to cereal grain crops purpose grown for human consumption compared to those grown for livestock feed because of a lack of sufficient data. We predicted water use (and other impacts) associated with cotton seed by applying an economic allocation process to divide impacts between the seed and lint. Irrigation rates were based in Australian industry averages and took into account the small amount of cotton grown without irrigation.

Livestock drinking water sources

Few data have been collated on the sources of water used for livestock drinking water in Australia. This is a critical element of the study because losses vary greatly (from close to zero for bore-tank-trough systems, to more than 10 fold for dams). To develop a dataset of water sources by region and the change in water sources over time we surveyed industry experts across all major production regions. The results of this survey are reported in Table 21 to Table 27 and were applied in the study.

Table 21 – Sources of water supply for farms in NHRZ

Drinking water source (%)	1981-86	1986-91	1991-96	1996-01	2001-06	2006-11
Bore	50.0	50.0	50.0	50.0	50.0	50.0
Uncapped	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Capped to open storage	*15.0*	*10.0*	*10.0*	*10.0*	*5.0*	*5.0*
Capped to closed storage	*35.0*	*40.0*	*40.0*	*40.0*	*45.0*	*45.0*
Reticulated Supply	0.0	0.0	0.0	0.0	0.0	0.0
Dam	25.0	25.0	25.0	25.0	25.0	25.0
Watercourse	24.5	24.5	24.5	24.5	24.5	24.5
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**

Table 22 – Sources of water supply for farms in SHRZ

Drinking water source (%)	1981-86	1986-91	1991-96	1996-01	2001-06	2006-11
Bore	22.7	22.8	22.8	22.8	23.2	23.1
Uncapped	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Capped to open storage	*3.7*	*3.1*	*0.8*	*0.7*	*0.6*	*0.4*
	0.163	*0.134*	*0.035*	*0.032*	*0.024*	*0.016*
Capped to closed storage	*19.0*	*19.7*	*22.0*	*22.1*	*22.6*	*22.7*
	0.8	*0.9*	*1.0*	*1.0*	*1.0*	*1.0*
Reticulated Supply	1.3	1.3	1.3	1.3	0.8	0.8
Dam	65.0	65.0	65.0	65.0	65.0	65.0
Watercourse	10.0	10.0	10.0	10.0	10.0	10.0
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**

Table 23 – Sources of water supply for farms in NTZ

Drinking water source (%)	1981-86	1986-91	1991-96	1996-01	2001-06	2006-11
Bore	57.0	57.0	57.0	57.0	57.0	57.0
Uncapped	*57.0*	*57.0*	*57.0*	*51.3*	*28.5*	*5.7*
Capped to open storage	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Capped to closed storage	*0.0*	*0.0*	*0.0*	*5.7*	*28.5*	*51.3*
Reticulated Supply	0.0	0.0	0.0	0.0	0.0	0.0
Dam	29.5	29.5	29.5	29.5	29.5	29.5
Watercourse	13.5	13.5	13.5	13.5	13.5	13.5
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**

Table 24 – Sources of water supply for farms in STZ

Drinking water source (%)	1981-86	1986-91	1991-96	1996-01	2001-06	2006-11
Bore	40.2	37.0	36.9	37.6	39.0	43.8
Uncapped	*5.0*	*5.0*	*5.0*	*3.6*	*2.0*	*0.4*
Capped to open storage	*5.1*	*5.1*	*4.5*	*2.5*	*1.3*	*2.1*
Capped to closed storage	*30.0*	*26.8*	*27.4*	*31.5*	*35.7*	*41.4*
Reticulated Supply	3.1	3.1	3.1	2.5	2.5	2.3
Dam	45.5	47.1	47.1	47.1	46.4	42.5
Watercourse	11.2	12.8	12.8	12.8	12.2	11.4
Total (%)	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 25 – Sources of water supply for farms in TNPZ

Drinking water source (%)	**1981-86**	**1986-91**	**1991-96**	**1996-01**	**2001-06**	**2006-11**
Bore	44.3	44.3	44.3	44.3	44.3	44.3
Uncapped	*11.3*	*11.3*	*11.3*	*10.1*	*5.6*	*1.1*
Capped to open storage	*23.3*	*18.3*	*15.3*	*8.0*	*5.8*	*4.3*
Capped to closed storage	*9.8*	*14.8*	*17.8*	*26.1*	*32.8*	*38.9*
Reticulated Supply	10.5	10.5	10.5	10.5	10.5	10.5
Dam	7.8	7.8	7.8	7.8	7.8	7.8
Watercourse	37.5	37.5	37.5	37.5	37.5	37.5
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**

Table 26 – Sources of water supply for farms in CNPZ

Drinking water source (%)	**1981-86**	**1986-91**	**1991-96**	**1996-01**	**2001-06**	**2006-11**
Bore	90.3	90.3	90.3	90.3	90.3	90.3
Uncapped	*90.3*	*90.3*	*90.3*	*81.2*	*45.1*	*9.0*
Capped to open storage	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Capped to closed storage	*0.0*	*0.0*	*0.0*	*9.0*	*45.1*	*81.2*
Reticulated Supply	0.0	0.0	0.0	0.0	0.0	0.0
Dam	4.0	4.0	4.0	4.0	4.0	4.0
Watercourse	5.8	5.8	5.8	5.8	5.8	5.8
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**

Table 27 – Sources of water supply for farms in SPZ

Drinking water source (%)	1981-86	1986-91	1991-96	1996-01	2001-06	2006-11
Bore	68.8	68.8	68.8	68.8	68.8	68.8
Uncapped	*68.8*	*68.8*	*68.8*	*61.9*	*34.4*	*6.9*
Capped to open storage	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Capped to closed storage	*0.0*	*0.0*	*0.0*	*6.9*	*34.4*	*61.9*
Reticulated Supply	0.0	0.0	0.0	0.0	0.0	0.0
Dam	21.3	21.3	21.3	21.3	21.3	21.3
Watercourse	10.0	10.0	10.0	10.0	10.0	10.0
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**

Table 28 and Table 29 show the irrigation water sources for the northern and southern backgrounding and finishing cattle.

Table 28 – Sources of water supply for backgrounding & finishing farms in northern region

Drinking water source (%)	1981-86	1986-91	1991-96	1996-01	2001-06	2006-11
Bore	68.3	68.3	68.3	68.3	68.3	68.3
Uncapped	56.0	56.0	56.0	50.4	28.0	5.6
Capped to open storage	5.7	4.2	3.8	2.7	1.6	1.4
Capped to closed storage	6.6	8.1	8.6	15.2	38.7	61.4
Reticulated Supply	1.6	1.6	1.6	1.6	1.6	1.6
Dam	14.6	14.6	14.6	14.6	14.6	14.6
Watercourse	15.5	15.5	15.5	15.5	15.5	15.5
Total (%)	100.0	100.0	100.0	100.0	100.0	100.0

Table 29 – Sources of water supply for backgrounding & finishing farms in southern region

Drinking water source (%)	1981-86	1986-91	1991-96	1996-01	2001-06	2006-11
Bore	33.1	32.1	32.1	32.3	33.0	34.6
Uncapped	8.5	8.5	8.5	7.4	4.1	0.8
Capped to open storage	3.8	3.4	2.0	1.3	0.7	0.9
Capped to closed storage	20.8	20.1	21.6	23.7	28.2	32.9
Reticulated Supply	1.8	1.8	1.8	1.5	1.3	1.2
Dam	54.1	54.6	54.6	54.6	54.4	53.1
Watercourse	11.2	11.4	11.5	11.4	11.3	11.1
Total (%)	100.0	100.0	100.0	100.0	100.0	100.0

Farm water supply loss factors

Bore losses

The Great Artesian Basin is one of the most extensive groundwater sources for Queensland, New South Wales and South Australia. Artesian bores provide a relatively low-cost water supply, however water losses from uncapped or damaged bores are very high. Approximately 90% of the water flowing into uncontrolled bores is lost through evaporation and seepage, with only 10% actually being consumed (DERM 2011).

The Great Artesian Basin Sustainability Initiative (GABSI) provides farmers with access to financial aid to rehabilitate uncontrolled bores. Funding under this initiative became available for landholders in 1999 (DERM 2011). The process involves capping the bore i.e. replacing the uncapped bore with a piped reticulation system. Capped bores were assumed to flow either to open storage i.e. a turkeys nest or closed storage i.e. water tank.

With regards to the trends in capped versus uncapped bores, it was assumed that the fraction of bores capped before GABSI (pre 1999), is fixed at 0. Table 30 shows the trend in the proportion of capped bores over the thirty year period of this study.

Table 30 – Proportion of capped artesian bores over time

Year	Proportion of capped bores
1981-86	0%
1986-91	0%
1991-96	0%
1996-2001	10%
2001-2006	50%
2006-2011	90%

Table 31 shows the bore loss factors assumed in this study.

Table 31 – Bore loss factors

Type of Bore	Bore Loss Factor
Uncapped	90%
Capped to open storage	50%
Capped to closed storage	5%

Dam losses

Evaporation losses from farm dams were calculated using a simplified dam water balance model for each region. The dam water balance model predicted the total losses from evaporation and seepage as a measure of total water extracted from the environment. Dam demand factors (the measure of annual water use as a proportion of total dam storage) were determined from surveys of farm water supply use and annual evaporation in Wiedemann et al. (*in preparation*). Dam efficiency, measured as a ratio of water intercepted from the environment to water used for drinking, varied between regions. Dam demand factors and intercept ratios are reported in Table 32.

Table 32 – Demand factors and water intercept ratios for farm dams

System	Dam Demand Factors	Intercept to extraction ratio
Region 1 - NHRZ	0.07	7.8
Region 2 - SHRZ	0.10	4.5
Region 3 - NTZ	0.07	6.7
Region 4 - STZ	0.07	5.8
Region 5 -TNPZ	0.05	7.3
Region 6 - CNPZ	0.05	12.6
Region 7 - SPZ	0.05	11.8
Northern region - aggregate	0.05	8.9
Southern region - aggregate	0.07	5.1
Uncertainty (SD)	-	1.45

Feedlot water use

In the feedlot, water is primarily used for drinking and cleaning. It is very difficult to disaggregate these water 'uses' at a commercial feedlot. Water use was modelled using Winchester & Morris (1956) for predicting drinking water, and Davis et al. (2009) for uses other than drinking water. Changes in local hydrology as a result of the feedlot site have previously been described by Wiedemann et al. (2013a, 2013b). This resulted in minimal additional water use and was excluded from the present study.

As with the farms, feedlots access water from creeks, bores, reticulated supplies or on-site storage dams; however the proportion of supply did not follow the same trends. One major difference was that feedlots do not use uncapped bores as a supply source. Table 33 show the different sources for water supply, along with the proportion of total water supplied by each, for both the northern and southern feedlots. These water supply proportions were determined from industry input and expert opinion. The sources have different levels of supply efficiency; however they are not the same as the factors used for farms due to difference in management practices.

Table 33 – Sources of water supply for feedlots

Drinking water source (%)	1985-86	1990-91	1995-96	2000-01	2005-06	2010-11
Northern Region						
Water sourced from bore	35%	39%	44%	49%	54%	60%
Capped to open storage	27%	29%	30%	32%	34%	36%
Capped to closed storage	8%	11%	13%	16%	20%	24%
Water sourced from creek	29%	27%	25%	23%	21%	18%
Direct supply from supply dam	36%	33%	31%	28%	25%	22%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Southern Region						
Water sourced from bore	35%	39%	44%	49%	54%	60%
Capped to open storage	27%	29%	30%	32%	34%	36%
Capped to closed storage	8%	11%	13%	16%	20%	24%
Water sourced from creek	29%	27%	25%	23%	21%	18%
Direct supply from supply dam	36%	33%	31%	28%	25%	22%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Bore loss factors were assumed to be 20% for bores pumping to open storages, and 5% for bores pumping to closed storages. Feedlot dam losses were calculated using the same method as the farm dams with intercept to extraction ratios of 3.5 used in both the northern and southern regions.

Appendix 4

Modelling GHG emissions

Grazing system enteric methane

Enteric methane was modelled using the DCCEE (2010b) methodology for pasture fed cattle in the temperate southern regions of Australia. This methodology is based on Blaxter and Clapperton (1965). This approach requires the estimation of gross energy intake and then calculates the fraction of this energy that is converted into methane based on the digestibility at maintenance of the feed energy and the level of feed intake relative to that required for maintenance. In order to determine the feed intake of the cattle, the equation derived by Minson and McDonald (1987) was used. This is then used to determine the gross energy intake and hence the enteric methane production.

In order to calculate feed intake (I_{ijkl} – kg dry matter/head/day) from live weight and live weight gain the following equation is used:

$$\boldsymbol{I_{ijkl} = (1.185 + 0.00454W_{ijkl} - 0.0000026W_{ijkl^2} + 0.315LWG_{ijkl})^2 \times MA_{ijkl=5}} \quad \textbf{Equation 1}$$

Where:

W_{ijkl} = live weight in kg

LWG_{ijkl} = live weight gain in kg/head/day

It is usual for feed intake to increase considerably when lactating occurs. The additional feed intake required during milk production is given by the equation:

$$\boldsymbol{MA_{ijkl=5} = \left(LC_{ijkl=5} \times FA_{ijkl=5}\right) + ((1 - LC_{ijkl=5}) \times 1)} \quad \textbf{Equation 2}$$

Where:

$LC_{ijkl=5}$ = proportion of cows>2 years old that are lactating

$FA_{ijkl=5}$ = feed adjustment (varies between 0 and 1.3 (DCCEE 2010b))

The gross energy content of feed dry matter is estimated to be 18.4 MJ/kg. Therefore, to determine the gross energy intake is found by multiplying the feed intake by this value:

$$\boldsymbol{GEI_{ijkl} = I_{ijkl} \times 18.4} \qquad \textbf{Equation 3}$$

The intake of the animals relative to that needed for maintenance is calculated using:

$$\boldsymbol{L_{ijkl} = I_{ijkl}/(1.185 + 0.00454W_{ijkl} - 0.0000026W_{ijkl^2} + (0.315 \times 0))^2} \qquad \textbf{Equation 4}$$

In order to determine the percentage of gross energy intake which yields enteric methane, the equation by Blaxter and Clapperton (1965) is used:

$$\boldsymbol{Y_{ijkl} = 1.3 + 0.112DMD_{ijkl} + L_{ijkl}(2.37 - 0.050DMD_{ijkl})} \qquad \textbf{Equation 5}$$

Where:

DMD_{ijkl} = digestibility of feed (%)

L_{ijkl} = feed intake relative to that needed for maintenance

Seasonal DMD values for pasture were based on the DCCEE (2010). Where these values did not align with cattle performance they were modified accordingly. The methane yields (kg CH_4/head/day) for pasture fed cattle in temperate regions are then found using:

$$\boldsymbol{M = \frac{Y_{ijkl}}{100} \times \frac{GEI_{ijkl}}{F}} \qquad \textbf{Equation 6}$$

Where:

F = 55.22 MJ/kg CH_4

For the enteric methane prediction from cattle in the tropical northern regions, the equations developed by Kennedy and Charmley (2012) were used. This study reported on 13 Brahman cattle fed 22 diets from combinations of five tropical grass species and five legumes and resulted in lower predictions of enteric methane than the equation currently applied in the Australian NGGI. None the less, the equation provides quite similar enteric methane predictions to those recommended by the IPCC (6% of GEI compared to 6.5%) and falls within the uncertainty range of ±1% recommended by the IPCC. This represents a large downward revision of the methane emissions that can be attributed to the northern Australian beef herd grazing tropical pastures. DMI was calculated using the equation by Minson and McDonald described previously.

Based on the study by Kennedy and Charmley (2012), the following regression equation was used to predict the enteric methane emissions from the cattle grazing on tropical pastures in Queensland:

$$\boldsymbol{CH_4\ yield = 19.6 \times DMI} \qquad \textbf{Equation 7}$$

Grazing System Manure Emissions

Manure Methane Emissions

The DCCEE (2010b) report that methane emissions from pasture fed cattle manure using the equation developed by Gonzalez-Avalos and Ruiz-Suarez (2001).

$$\boldsymbol{M = I \times (1 - DMD) \times MEF} \qquad \textbf{Equation 8}$$

Where:

M = methane yield (kg CH_4/head/day)

I = feed intake (kg dry matter/head/day) DMD = dry matter digestibility (%)

MEF = manure emission factor of 0.000014 for temperate regions, and 0.000054 for tropical regions - DCCEE (2010b).

Manure nitrous oxide emissions

Excreted nitrogen is rapidly lost to the atmosphere through a number of pathways. Of these, direct nitrous oxide emissions contribute directly to the GHG profile of cattle. Additionally, emissions of ammonia contribute to indirect GHG emissions when ammonia is deposited to surrounding land and re-emitted as nitrous oxide. Hence, both direct nitrous oxide emissions and ammonia emissions are important for the estimation of total GHG.

In order to calculate the nitrous oxide emissions from pasture fed cattle, it is first necessary to determine the nitrogen content of the excreted faeces and urine to pasture. This is found by calculating the crude protein content (CPI) and amount of nitrogen retained by the body (NR).

The crude protein intake CPI (kg/head/day) of beef cattle is calculated using:

$$\boldsymbol{CPI = I \times CP + (0.032 \times MC)}$$ **Equation 9**

Where:

I = dry matter intake (kg/head/day)

CP = crude protein content of feed dry matter expressed as a fraction

MC = milk intake (kg/head/day).

Nitrogen excreted in faeces (F kg/head/day) was determined using equation 10.

$$\boldsymbol{F = \left\{0.3\left(CPI \times \left(1 - \left[\frac{(DMD+10)}{100}\right]\right)\right) + 0.105(ME \times I \times 0.008) + 0.08(0.032 \times MC) + (0.0152 \times I)\right\}/6.25}$$ **Equation 10**

Where:

DMD = dry matter digestibility (expressed as a %)

ME = metabolise energy (MJ/kg DM)

I = feed intake (kg DM/head/day)

MC = milk intake (kg/head/day)

Table 34 shows the average annual crude protein content and pasture DMD for the regions modelled.

Table 34 – Dry matter crude protein (CP) content of pasture for breeding, backgrounding and grass finishing cattle

Region	CP (%)	DMD (%)
NHRZ	9%	58%
SHRZ	15%	68%
NTZ	9%	58%
STZ	12%	62%
TNPZ	8%	53%
CNPZ	8%	53%
SPZ	9%	58%
Northern	9%	55%
Southern	14%	66%

The quantity of nitrogen that is retained within the body (NR kg/head/day) is determined as the amount of nitrogen retained as body tissue and milk:

$$\boldsymbol{NR = \Big\{(0.032 \times MP) + \Big\{0.212 - 0.008(L-2) - \Big[\big(0.140 - 0.008(L-2)\big)/\Big(1 + exp\big(-6(Z-0.4)\big)\Big)\Big]\Big\} \times (LWG \times 0.92)\Big\}/6.25} \quad \textbf{Equation 11}$$

Where:

MP = milk production (kg/head/day)

L = relative intake

Z = relative size (liveweight/standard reference weight)

LWG = liveweight gain (kg/day)

The amount of nitrogen excreted in urine (U) is found using the equation:

$$\boldsymbol{U = \left(\frac{CPI}{6.25}\right) - NR - F - \left[\frac{(1.1 \times 10^{-4} \times LW^{0.75})}{6.25}\right]} \quad \textbf{Equation 12}$$

Where:

LW = average seasonal liveweight of animal

The nitrous oxide emissions from faecal and urinary nitrogen voided onto pasture are calculated using:

$$\boldsymbol{N_2O\ emissions} = (\boldsymbol{F} + \boldsymbol{U}) \times \boldsymbol{MMS} \times \boldsymbol{EF}_{(\boldsymbol{MMS})} \times \boldsymbol{C_g}$$ **Equation 13**

Where:

MMS = the fraction of nitrogen that is voided to pasture – assumed to be 100%.

$EF_{(MMS)}$ = emissions factor (N_2O-N kg/N excreted). This is 0.005 for faeces and 0.004 for urine after the DCCEE (2010b).

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass.

Feedlot enteric methane

Feed intake for feedlot cattle was modelled in the same as the grass finished cattle. Enteric methane was modelled using the DCCEE (2010b) methodology for feedlot cattle, which is based on Moe and Tyrrell (1979). This approach requires the estimation of gross energy intake and then calculates the proportion of this energy that is converted into methane based on the digestibility at maintenance of the feed energy and the level of feed intake relative to that required for maintenance. The equations for methane emission require some detail regarding dietary components, specifically, the proportion of soluble residue, hemicellulose and cellulose in the diet.

The formula for enteric methane yield (Y– MJ CH_4/head/day) is as follows:

$$\boldsymbol{Y = 3.406 + 0.510SR + 1.736H + 2.648C}$$ **Equation 14**

Where:

SR = intake of soluble residue (kg/day)

H = intake of hemicellulose (kg/day)

C = intake of cellulose (kg/day)

Each of SR, H and C are calculated from the total intake of the animal, the proportion of the diet of each class of animal that is grass, legume, grain (including molasses) and other concentrates and the soluble residue, hemicellulose and cellulose fractions of each of these components.

Hence:

$$\boldsymbol{SR} = (\boldsymbol{I} \times \boldsymbol{P_{grain}} \times \boldsymbol{SR_{grain}}) + (\boldsymbol{I} \times \boldsymbol{P_{conc}} \times \boldsymbol{SR_{conc}}) + (\boldsymbol{I} \times \boldsymbol{P_{grass}} \times \boldsymbol{SR_{grass}}) + (\boldsymbol{I} \times \boldsymbol{P_{legume}} \times \boldsymbol{SR_{legume}})$$ **Equation 15**

$$\boldsymbol{H} = (\boldsymbol{I} \times \boldsymbol{P_{grain}} \times \boldsymbol{H_{grain}}) + (\boldsymbol{I} \times \boldsymbol{P_{conc}} \times \boldsymbol{H_{conc}}) + (\boldsymbol{I} \times \boldsymbol{P_{grass}} \times \boldsymbol{H_{grass}}) + (\boldsymbol{I} \times \boldsymbol{P_{legume}} \times \boldsymbol{H_{legume}})$$ **Equation 16**

$$\boldsymbol{C} = (\boldsymbol{I} \times \boldsymbol{P_{grain}} \times \boldsymbol{C_{grain}}) + (\boldsymbol{I} \times \boldsymbol{P_{conc}} \times \boldsymbol{C_{conc}}) + (\boldsymbol{I} \times \boldsymbol{P_{grass}} \times \boldsymbol{C_{grass}}) + (\boldsymbol{I} \times \boldsymbol{P_{legume}} \times \boldsymbol{C_{legume}})$$ **Equation 17**

Where:

I = intake (kg/day)

Pgrain = proportion of grains in feed

Pconc = proportion of concentrates in feed

Pgrass = proportion of grasses in feed

Plegume = proportion of legumes in feed

SR, H or C grain = soluble residue, hemicellulose or cellulose content of grain

SR, H or C conc = soluble residue, hemicellulose or cellulose content of other concentrates

SR, H or C grass = soluble residue, hemicellulose or cellulose content of grasses

SR, H or C legume = soluble residue, hemicellulose or cellulose content of legumes

The total daily production of methane, M_{ij} (kg CH_4/head/day) is thus:

$$\boldsymbol{M} = \boldsymbol{Y}/\boldsymbol{F}$$ **Equation 18**

Where:

F = 55.22 MJ/kg CH_4

The DCCEE provide default values for daily feed intake and feed properties for Australian feedlot cattle. However, for the feedlots under investigation, average data from previously modelled feedlots were available and were substituted into the equations described previously. Key differences between the DCCEE default assumptions and the actual data collected from the feedlot relate to daily dry matter intake (DMI) and the proportion of grain, grass, legume and concentrate in the diets. Table 35 shows the daily feed intake and feed properties for the feedlots used in this study.

Table 35 – Daily feed intake and feed properties for feedlots

			Domestic Feedlot Heifers (2010-11)	Domestic/Mid-fed Feedlot Steers (2010-11)	Long-fed Feedlot Steers (2010-11)
Daily Intake (assume DMI)	(kg/day)	8.9	9.8	10.8	10.2
Proportion of grains in feed	(%)	77.9	79.0	79.0	68.9
Proportion of concentrates in feed	(%)	4.8	10.3	10.3	9.7
Proportion of grasses in feed[1]	(%)	13.8	9.8	9.8	21.0
Proportion of legumes in feed	(%)	3.5	1.0	1.0	0.1
Enteric methane production	(kg/hd/yr)	0.180	0.189	0.201	0.210

[1] forage hay / silage classified under grasses

Feedlot manure emissions

Greenhouse gas emission estimation from manure management relies on the prediction of specific manure properties; excreted volatile solids (VS) and nitrogen (N). Other nutrient components of manure are also relevant for estimating nutrient by-product value in manure.

We applied a mass balance approach to predict excreted manure components and emissions throughout the manure management system. Mass balance modelling was done with the BeefBal model (QPIF 2004) based on inventory data from seven Australian feedlots (Davis et al. 2009) reporting feed intake, growth rates and rations. From these data, predicted excreted VS and N were predicted. The mass balance followed emission losses throughout the feedlot system after Watts et al. (2012), including losses from the feedpad, stockpile, ponds and land application. Key emission factors are reported in Table 36.

Table 36 – Manure GHG parameters used for feedlot cattle

Emission source	Key parameters / model	Reference
Feedpad manure methane	M (kg/hd) = VS (kg/head) x 0.17 m^3 CH_4/kg VS (B_o) x MCF (1.5-5% depending on region) x 0.622 kg/m^3 (*p*)	DCCEE (2010b)
Feedpad manure nitrous oxide	Manure N – 0.01 kg N_2O-N / kg N in manure.	Muir (2011)
Manure and effluent ammonia (all sources)	0.81 kg NH_3-N / kg N of excreted in manure	Watts et al. (2012)
Indirect nitrous oxide from ammonia losses	0.01 kg N_2O-N / kg NH_3-N volatilised	DCCEE (2010b)
Indirect nitrous oxide from leaching and runoff	0.0125 kg N_2O-N / kg NO_3-N lost in leaching and runoff	DCCEE (2010b)
Nitrous oxide – land application	0.01 kg N_2O-N / kg N land applied	DCCEE (2010b)

Leaching and runoff

The deposition of manure and urinary nitrogen on pastures can be lost through leaching and runoff and subsequently released as nitrous oxide to the atmosphere. The mass of animal waste N applied to soils through leaching and runoff is calculated using the following equation (DCCEE 2010b):

$$\boldsymbol{Waste_N = (MN_{soil} + UN_{soil} + FN_{soil}) \times FracWET \times FracLEACH} \qquad \textbf{Equation 19}$$

Where:

MN_{soil} = mass of manure N applied to soil

UN_{soil} = mass of urinary N applied to soil

FN_{soil} = mass of faecal N applied to soil

FracWET= fraction of N available for leaching and runoff (varies across each region)

FracLEACH = 0.3 (kg N/kg applied) IPCC default fraction of N lost through leaching and runoff

FracWET for each region was calculated using the values provided by the DCCEE for each state (Table 37). These state values were then used to determine the regional values shown in Table 38 and Table 39 based on an average of the relevant state values for each region.

Table 37 – Fraction of animal waste available for leaching and runoff (FracWET)

State	Grazing Beef Cattle
ACT	0.785
NSW	0.365
NT	0.237
QLD	0.114
SA	0.691
TAS	0.997
VIC	0.914
WA	-
WA – South West	0.823
WA – Pilbara	0.089
WA – Kimberley	0.381

Table 38 – FracWET for grazing cattle (breeding herd)

Region	NHRZ	SHRZ	NTZ	STZ	TNPZ	CNPZ	SPZ
Free range cattle – FracWET	0.11	0.91	0.11	0.67	0.24	0.15	0.58

Table 39 – FracWET for grazing cattle (backgrounding & Finishing herd)

Region	Northern	Southern
Free range cattle – FracWET	0.16	0.79
Feedlot cattle – FracWET	0.07	0.19

The nitrous oxide emissions which occur as a result of this leaching and runoff are then calculated from:

$$\boldsymbol{Nitrous\ oxide\ emissions = Waste_N \times EF \times C_g} \qquad \textbf{Equation 20}$$

Where:

EF = 0.0125 (kg N_2O-N/kg N)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Summary of GHG calculation methods and factors

The parameters and equations used in this study to determine the GHG emissions from grazing and feedlot beef are summarised in Table 40 and Table 36, along with the assumed uncertainty.

Table 40 – Key GHG parameters used for grazing cattle

Emission source	**Key parameters / model**	**Reference**
Enteric methane (Temperate)	M = (Y/100) x (GEI/F)	DCCEE (2010b) – from Blaxter and Clapperton (1965)
Enteric methane (Tropical)	M = 19.6 x DMI	Kennedy & Charmley (2012)
Enteric methane (feedlot cattle)	M (kg/hd) = (3.406 + 0.510SR + 1.736H + 2.648C) / F (MJ / kg CH_4)	DCCEE (2010) – from Moe and Tyrrell (1979)
Grazing cattle -Manure methane	M (kg/hd) = DMI x (1 - DMD) x MEF	DCCEE (2010b)
Grazing cattle - Manure nitrous oxide	Urinary N – 0.004 kg N_2O-N / kg N in urine. Faecal N – 0.005 kg N_2O-N / kg N in faeces.	DCCEE (2010b)
Feedlot feedpad manure nitrous oxide	Manure N – 0.01 kg N_2O-N / kg N in manure.	Muir (2011)
Feedlot manure and effluent ammonia (all sources)	0.81 kg NH_3-N / kg N of excreted in manure	Watts et al. (2012)
Grazing cattle- Manure ammonia	0.2 kg NH_3-N / kg N of excreted in manure	DCCEE (2010b)
Indirect nitrous oxide from ammonia losses	0.01 kg N_2O-N / kg NH_3-N volatilised	DCCEE (2010b)
Indirect nitrous oxide from leaching and runoff	0.0125 kg N_2O-N / kg NO_3-N lost in leaching and runoff	DCCEE (2010b)

Appendix 5

Land and climate supplementary information

National land and water resources audit beef production regions

The NLWRA includes a description of the 6 Beef Production regions including statistics on cattle numbers and areas of pasture. These data were found to be too unreliable to use in the LCA study but are discussed here to illustrate the difficulty in getting accurate data even from what would appear to be highly credible sources. As an illustration of the reasons for lack of confidence in the data, the beef cattle numbers add up to approximately 44.5 million head for the reference year of 1999 which is inconsistent with ABS and industry data that show that the total herd has not exceeded 33 million head at any time.

Table 41 provides summary data for production characteristics in 1997 of each of the base ANRA regions as reported in the National Land and Water Resources Audit (NLWRA). NLWRA estimated that the more productive lands in the southern high rainfall and temperate regions can be stocked at 2 to 4 head per ha. Even with improved pastures and lucerne making up a larger proportion of grazing land, 4 head per hectare represents an unrealistically high stocking rate and caution is urged in accepting these data. In the pastoral zone grazing native pastures underpins beef production systems and stocking rates on specialist beef enterprises are estimated as being low with up to 10ha per head required. The inconsistency of these data with industry accepted stocking rates illustrates why they weren't used in the present analysis.

Table 41 –Area of beef production and indicative stocking rates for each of the six ANRA regions as presented in the National Land and Water Resources Audit for 1997

ANRA region	Area (ha)	Specialist beef enterprise Cattle (hd)	Specialist beef stocking rate (hd/ha)	Av property size (ha)	Ratio native to sown pasture areas	Area lucerne pastures (ha)
Northern High Rainfall	6,634,626	1,203,760	1.8	9,076	1.8	780
Northern Temperate	6,304,595	1,344,926	1.8	11,255	1.5	1,070
Northern Pastoral	145,565,201	5,006,340	0.3	114,626	27.3	1,053
Southern High Rainfall	7,832,294	3,809,750	4.2	720	1.0	142,144
Southern Temperate	9,044,788	2,227,548	2.0	1,825	1.5	331,017
Southern Pastoral	44,319,282	679,455	0.1	225,558	62.8	2,256

Analysis of land use change by ANRA region

In the methodology we described an attempt to use data prepared for Australia's National Carbon Accounting System (NCAS) on Land Use Change by state IBRA region in five year time periods from 1975 to 2000. It was clear from the description of these analyses by different state expert groups that there was a very high uncertainty in the data. Nevertheless we spent considerable time and effort extracting the best data possible from the NCAS report as it was the only potential source identified that could provide data consistent with the beef herd statistics used in the LCA study. However comparison with National Greenhouse Gas Inventory reports and SLATS reports for Queensland led to the conclusion that the NCAS report data were too inaccurate for analysis for this project. Therefore no conclusions could be based on the data on LUC by ANRA region and subsequently alternative analysis was undertaken using state and national data, primarily based on satellite imagery detection of woody vegetation clearing.

Table 42 – Results of analysis of LUC greenhouse gas emissions by modified ANRA region for the five-year time periods from 1975 to 2000 based on NCAS reported figures prior to availability of national remote sensing data

Modified ANRA Region	1975-80	1980-85	1985-90	1990-95	1995-2000
	GHG (t CO2-e/yr)				
Northern temperate	920,528	994,956	1,193,262	1,483,127	1,833,289
Southern High Rainfall (Qld)	298,345	322,467	397,500	465,303	547,956
Eastern Southern Temperate	16,526,042	17,862,221	18,599,470	19,156,666	19,962,221
Southern Pastoral	7,573,787	7,430,292	7,187,461	6,872,442	6,615,029
Northern High Rainfall	65,212	70,485	107,783	162,087	226,725
Central Northern pastoral	72,345	78,194	81,204	85,247	90,665
Tropical Northern Pastoral (Qld)	-159,323	855,551	828,060	798,081	765,379
Southern High Rainfall West	2,282,141	2,188,655	2,082,513	1,997,981	1,881,711
West Southern temperate	20,836,535	19,937,465	18,989,552	17,958,493	16,904,626
Southern High Rainfall Zone East	0	43,438	41,152	41,152	43,438
Total	48,415,612	49,783,724	49,507,956	49,020,579	48,871,039

Note 1: *Analysis using national and state GHG emissions and LUC data*

Note 2: An expanded disaggregation of the ANRA regions used in the LCA study were used in this analysis in an attempt to reduce the uncertainty due to variation within regions.

The NLWRA (2001) included an attempt to quantify the intensification of various agricultural commodities for the period 1983 to 1997 using an index calculated as:

_L_i x F_I

where L_i are the proportions of the different land use categories in each region, and F_i are the corresponding intensity factors.

The intensity factor was based upon the average cost of production, as a surrogate for the level of intensity of land use, for 1991-1994 taken from the ABS Farm Financial Survey (see Figure 41).

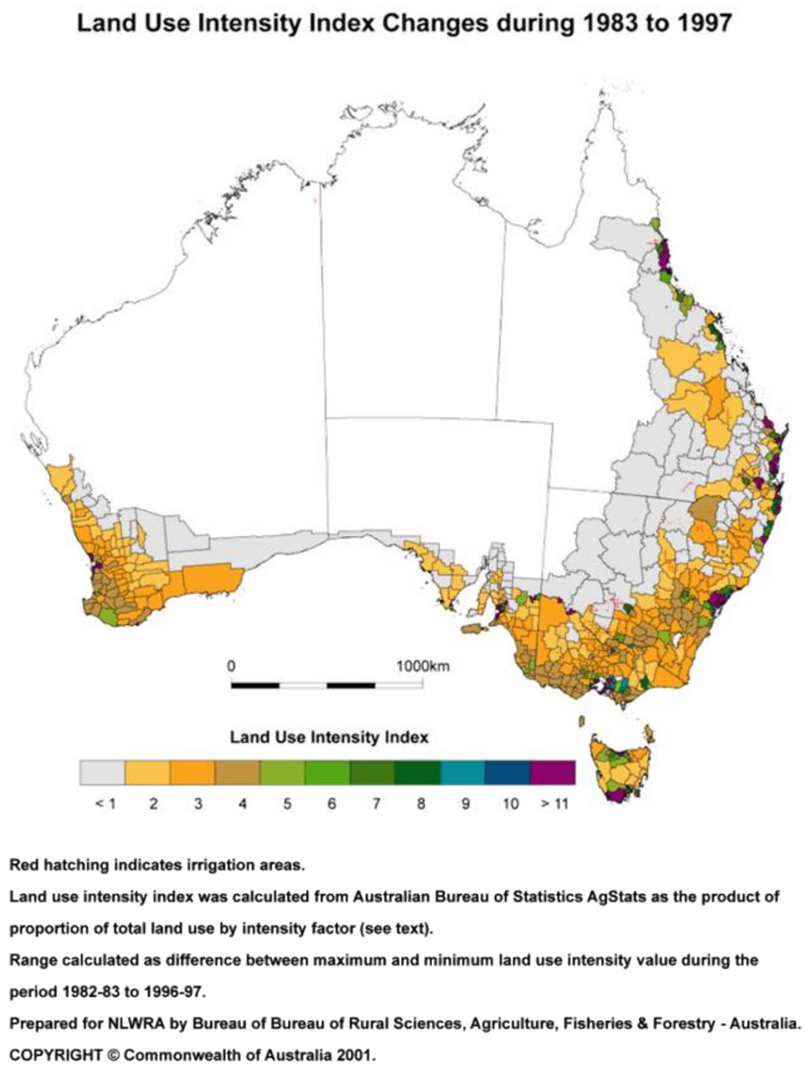

Figure 41 - (reproduced from NLWRA 2001). The range (maximum less minimum) in values of agricultural land use Intensity Index that occurred during 1982-83 to 1996-97

Land use disaggregated by quality for production

In this project Net Primary Productivity (NPP) was evaluated as a means of categorising land according to its 'quality' and hence to provide a more accurate assessment of the impact of land occupation for beef production than simply the total number of hectares used for grazing and feed production. The value of NPP as an indicator however depends on its accurate quantification. Empirical estimates of NPP are difficult, expensive and time consuming (e.g. Clark et al. 2001, Scurlock et al. 2002), and there is no national coverage of measured NPP. Currently the only feasible source of spatially consistent data is mathematical modelling (Roxburgh et al. 2004). Roxburgh et al. (2004) compared results from twelve Australian NPP models. In this project we use outputs from the AussieGRASS spatial implementation of the GRASP model (Carter et al. 2000, 2010; Rickett et al. 2000). The GRASP pasture growth and water balance model has been parameterised using extensive grazing trial data and nationally extensive observations. It was the preferred model not only because of its extensive validation over two decades but because of its national coverage and development specifically for the rangelands and grazed woodlands of northern Australia that have the largest percentage of the national herd. To estimate NPP this physiological plant growth model aggregated over a year the lesser of daily water-use and radiation-use efficiency based calculations using SILO daily climate data (Jeffrey et al. 2001). Access to the NPP datasets was from http://www.steverox.info/software_downloads.htm. AussieGRASS applies the GRASP model on a 5km grid nationally. Importantly, AussieGRASS predicted NPP based on 'current' vegetation cover, i.e. including post-clearing and agricultural activity. Hence it gives a conservative but defensible simulation of regional NPP with the continental value falling in the mid-range of estimates in the 12 models compared by Roxburgh et al. (2004). In this project we applied a map of Statistical Local Area (SLA) boundaries and took the centroid value of NPP for each SLA. Using a simple averaging method the mean and standard deviation of NPP was derived for each Statistical Division nationally. An indicative value of NPP was then calculated for each of the modified ANRA regions (Figure 46). These are shown in noting that the regions have been further disaggregated from the 7 used in the LCA analysis in this study to illustrate the difference in productivity as indicated by NPP within some regions.

Table 43 – Net Primary Productivity of each of the modified ANRA regions

ANRA-derived regions	NPP	St Dev
Northern High Rainfall Zone	399.39	91.57
Western Southern High Rainfall Zone	477.24	52.96
South-eastern Southern High Rainfall Zone	963.07	193.22
North Southern High Rainfall Zone[1]	380.63	44.83
Northern Temperate Zone	426.11	76.52
Eastern Southern Temperate Zone	682.09	279.99
Western Southern Temperate Zone	352.12	199.23
Tropical Northern Pastoral Zone	233.94	132.01
Central Northern Pastoral Zone	216.64	140.59
Southern Pastoral Zone	233.82	81.90

[1] The northern (Queensland) part of the Eastern Southern High Rainfall Zone is presented separately to that for southern states because it was significantly different in NPP.

Change in stocking rate of sheep and cattle as an indicator of land clearing for beef production

In most cases the primary agricultural commodity for post-clearing production was not provided. In particular clearing for pasture or grazing did not distinguish between sheep and cattle as the major production species. Figure 42 shows the total grazing density in Australia by Statistical Local Area in the rangelands for the decades from 1950s to 1990s. The ratio of cattle to sheep represented spatially for 1976 (See Figure 14) provides a baseline distribution for relative numbers. Stocking density for each species, given in Figure 44 to Figure 46, show the trends in distribution. Expressed as Dry sheep equivalents these data enable an approximate split of 'pasture intake' between the species to then enable allocation of land use change. With falling sheep numbers and most clearing (>80%) since 2000 being in Queensland, it is reasonable to assume that all clearing for pasture in the final 10 years of the analysis period (post 2000) being for beef cattle production. In summary, beef cattle density increased in Queensland, New South Wales, South Australia and the Northern Territory in the mid- to late-1970s; in this period, sheep density fell in all States. Sheep density peaked again in the early 1990s. Cattle density increased by 50% across Australia from 1956 to 1999 while sheep density fell to half of what it was in the 1950s.

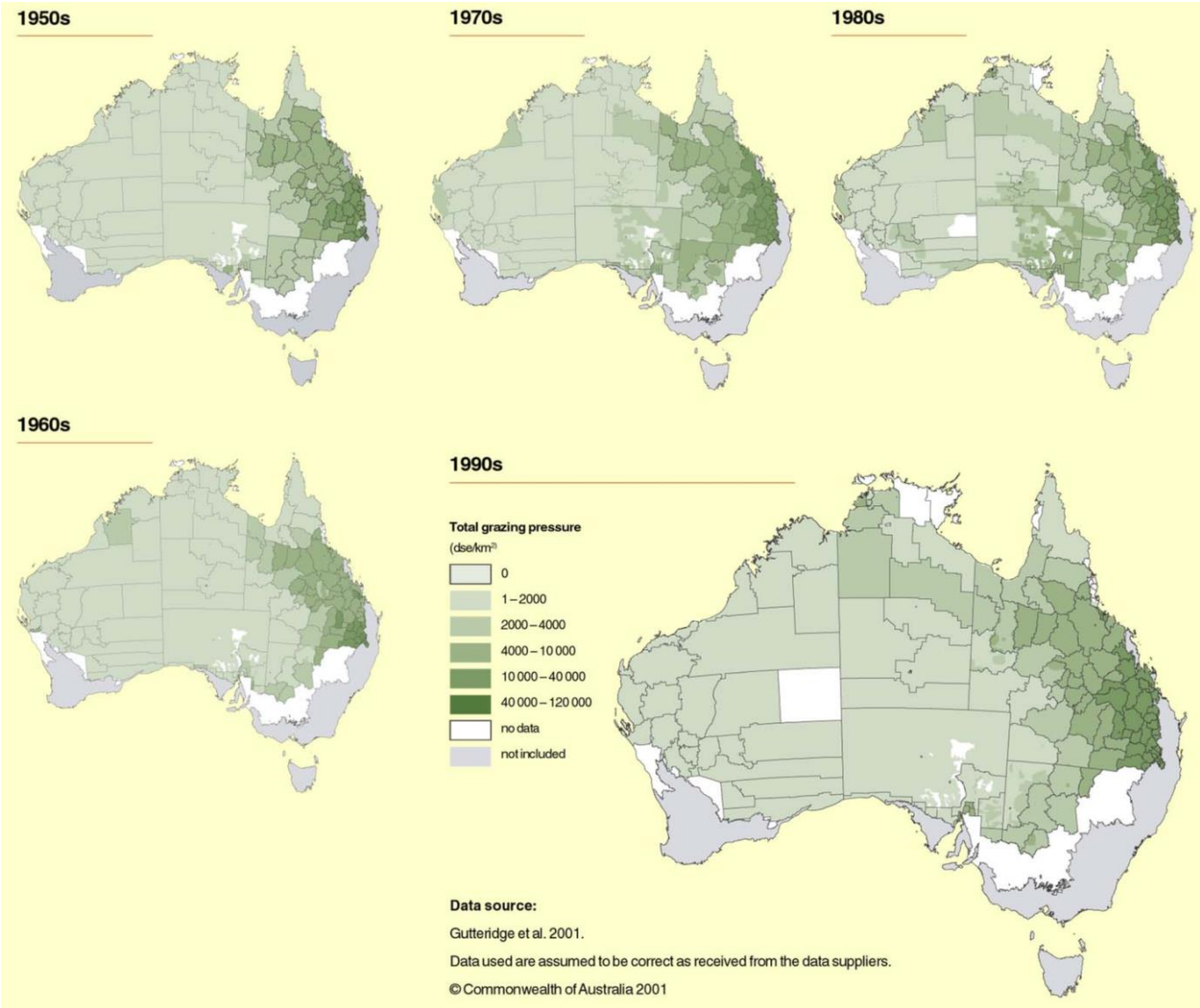

Figure 42 - Total grazing density for Australia's rangelands by statistical local area (1950s, 1960s, 1970s, 1980s, 1990s)

Figure 43 - Density of cattle in All regions of Australia, by decade from the 1950s to 1990s (http://www.anra.gov.au/topics/rangelands/pubs/tracking-changes/impacts.html)

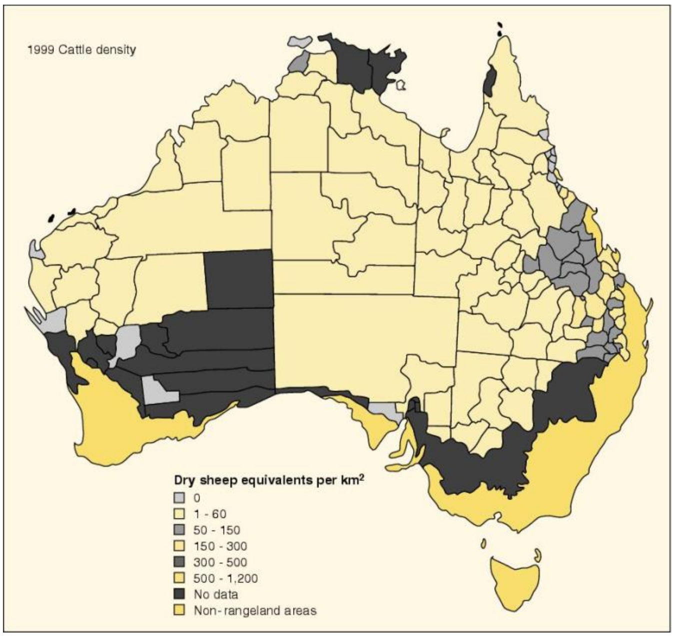

Figure 44 - Density of cattle in Australian rangelands in 1999 expressed as DSE (1 dry sheep equivalent (DSE)=a 45kg non-pregnant, non-lactating sheep)

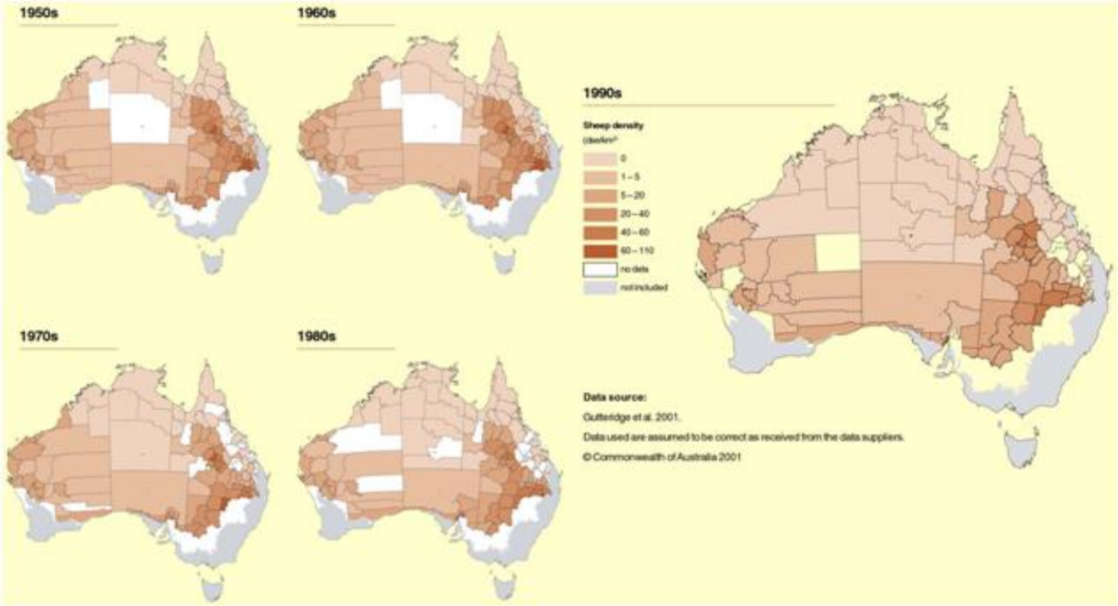

Figure 45 - Density of sheep in Australian rangelands by decade from the 1950s to 1990s

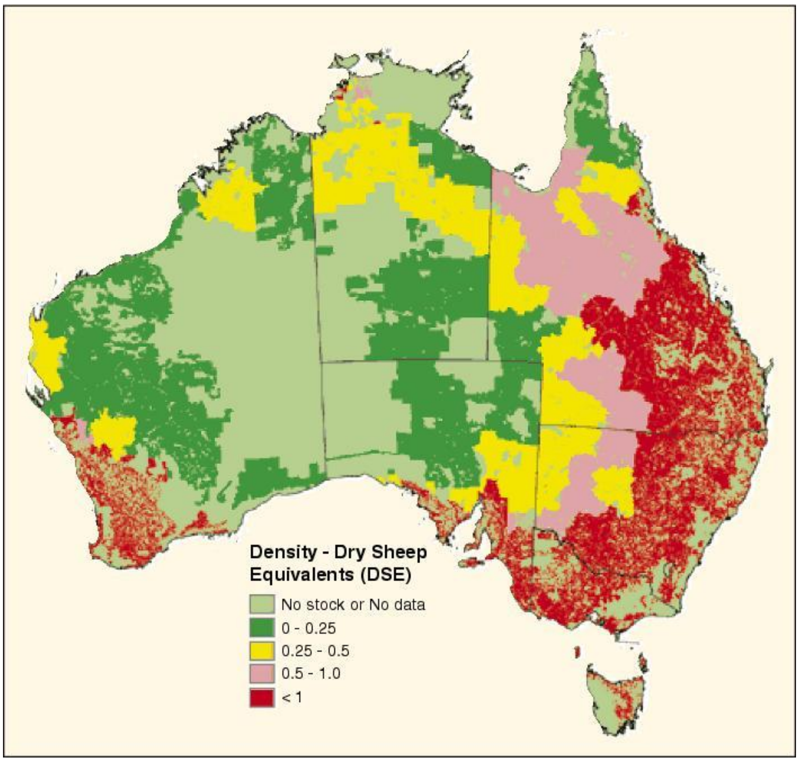

Figure 46 - Density of sheep in all regions of Australia for 1999 expressed as DSE. (1 dry sheep equivalent (DSE)= a 45kg non-pregnant, non-lactating sheep)

Land resource data

Table 44 Feed production data

	1981-85	1986-90	1991-95	1996-2000	2001-05	2005-10
Area Harvested (Ha)						
Grasses/Forage	934,224	1,459,400	1,123,000	1,277,400	652,800	550,000
Cereals Total	17,385,019	13,968,067	13,071,928	16,764,750	18,858,240	19,779,232
Coarse Grain Total	5,255,792	4,428,430	4,760,923	5,136,430	6,437,071	6,709,333
	r					
Production (tonnes)						
Grasses/Forage	3,882,036	8,720,000	11,220,000	18,754,000	8,980,000	7,000,000
Cereals Total	24,500,702	22,242,619	22,723,142	34,007,529	34,787,948	29,408,725
Coarse Grain Total	7,390,381	7,173,100	8,258,527	10,395,609	12,426,703	11,198,589
Yield (kg/Ha)						
Grasses/Forage	3,947	5,978	10,017	14,640	13,612	12,727
Cereals Total	1,397	1,596	1,723	2,029	1,838	1,478
Coarse Grain Total	1,389	1,624	1,717	2,030	1,928	1,671

Table 45 Cattle and sheep numbers expressed as DSE.

	Stock numbers (Millions DSE)					
	1981-85	**1986-90**	**1991-95**	**1996-2000**	**2001-05**	**2005-10**
Cattle	187.3571	180.4769	196.9486	214.6806	220.6448	221.425187
Sheep	138.9218	156.0552	140.5947	118.5686	103.7461	79.5004726
Total	326.2789	336.5322	337.5433	333.2493	324.3909	300.92566

Table 46 Land resources relevant to beef production

	1981-85	1986-90	1991-95	1996-2000	2001-05	2005-10
Land area	768230	768230	768230	768230	768230	768230
Agricultural area	475589.2	469149.2	464377.2	460087.2	445491.8	417054.2
Arable land/crops	45845.2	47452.4	45507.6	42860	48689.6	45489.6
Permanent grasslands and pastures	429744	421696.8	418869.6	417227.2	396802.2	371564.6
Forest and other	292640.8	299080.8	303852.8	308142.8	322738.2	351175.8

Land use change data

Table 47 Annual rates of deforestation

Annual clearing rate for beef production (ha)						
	1981-85	1986-90	1991-95	1996-2000	2001-05	2006-10
QLD	270,000	427,500	252,646	239,504	258,844	157,918
NSW	75,000	75,000	23,118	21,446	0	0
VIC	0	0	0	0	0	0
SA	0	0	0	0	0	0
WA	11,713	10,411	16,970	12,441	19,991	24,745
TAS	600	600	0	0	0	0
NT	13,014	13,014	746	765	894	1,437
	370,327	526,525	293,481	274,156	279,729	184,100

Table 48 Greenhouse gas emissions estimated for Land Use Change for beef production

	GHG emissions (Mt CO_2-e per year)					
	1981-85	**1986-90**	**1991-95**	**1996-2000**	**2001-05**	**2006-10**
QLD	32.133	50.877	35.155	32.019	34.007	22.195
NSW	10.771	10.771	5.474	4.705	1.018	0.572
VIC	0.000	0.000	0.000	0.000	0.000	0.000
SA	0.000	0.000	0.000	0.000	0.000	0.000
WA	0.668	0.594	0.968	0.709	1.140	1.411
TAS	0.046	0.046	0.000	0.000	0.000	0.000
NT	0.467	0.467	0.027	0.027	0.032	0.052
Total	44.086	62.756	41.624	37.461	36.197	24.230

Soil carbon losses are known to have occurred during the transition from pasture to cultivation for Australia's cereal cropping regions (Dalal & Chan 2001). To estimate soil carbon losses, we determined the total land utilised for cropping in each region across the time period, based on grain and concentrate use in the herd (including feedlots), and the average yields for cereal grains and hay in each region over the time period. Soil carbon losses were determined using the regression equation of Dalal & Chan (2001) which has been used previously to estimate total soil carbon losses in Australia's crop lands. We applied soil carbon losses at the loss rates indicated by Dalal & Chan (2001) only for the proportion of crop land managed with cultivation in each region, based on the survey by the ABS (2009). Soil carbon levels in crop land managed with zero tillage were assumed to be maintained at a steady state without further losses.

Table 49 – Cultivated land occupation for the Australian beef cattle herd for the period 1980-2011

		1986	**1991**	**1996**	**2001**	**2006**	**2011**
CQ grain growing region	ha	31002	62926	112039	161010	234554	154239
southern QLD / nth NSW grain growing region	ha	100373	153328	282982	550348	525907	733353
sth NSW / VIC grain growing region	ha	53228	77775	138100	275174	458620	550717
SA grain growing region	ha	20911	31943	59186	91725	108103	134208
WA grain growing region	ha	22305	34073	59186	117932	127180	142596
Total Ha	ha	227818	360046	651493	1196188	1454365	1715114

Table 50 – Soil carbon loss (tonnes CO_2 per year) due to conversion to cultivation in the major grain growing regions of Australia

		1986	1991	1996	2001	2006	2011
CQ grain growing region	t CO_2-e	30692	62297	110919	159400	232209	152696
southern QLD / nth NSW grain growing region	t CO_2-e	99369	151795	280152	544844	520648	726020
sth NSW / VIC grain growing region	t CO_2-e	52696	76997	136719	272422	454033	545210
SA grain growing region	t CO_2-e	20702	31624	58594	90807	107022	132866
WA grain growing region	t CO_2-e	22082	33732	58594	116752	125908	141170
Total	t CO_2-e	225540	356446	644978	1184226	1439821	1697963

Appendix 6

Methodologies for quantification of GHG emissions of products

Climate influences on Australia's beef production

Based on the LCA approach of ISO 14044, GHG emissions from Land Use Change (LUC) (also referred to in LCA studies as Land Transformation), where significant, should be included in quantification of GHG emissions from a product. GHG emissions occur due to the oxidation of carbon stored in wood or soils through burning or decomposition and its loss to the atmosphere, primarily as carbon dioxide. As in ISO TS 14067:2013, only direct land use change (dLUC) is included in quantification of the product GHG emissions in this beef impact analysis, and emissions are reported separately, reflecting the higher uncertainty and debate surrounding this component of total emissions. There are a number of policies and methodologies currently in use for assessing the GHG emissions of products (Table 4). The three most authoritative are PAS 2050:2011, WRI /WBCSD GHG Protocol Product Standard and ISO TS 14067 and over recent years there have been moves towards harmonisation of treatment of direct LUC in these as summarised below.

Table 51 – Selection of Government Sponsored and Private CFP Programs

Methodologies	Implementation policies
PAS 2050 (UK)	Ecocheck (Belgium)
GHG Protocol - Product Life Cycle Accounting and Reporting Standard (worldwide)	Ecological Bonus-Malus (France)
BP X30-323 (France)	The "Grenelle 2" Act (France)
ISO 14067 (worldwide)	The Korean PCF label (in the frame of the Korean EDP Program) (Korea)
Korea PCF (Korea)	Carbon Label for California (US)
Carbon Footprint Program (Japan PCF)	Carbon Label of Carbon Trust (UK)
Sustainability consortium (Wal-Mart)	Carbon Disclosure Project (worldwide)
Carbon index Casino (France)	Climate Bonus (Finland)
Greenext (Leclerc - France)	Cities for Climate Protection (CCP) Campaign(USA)
Food labelling SE (Sweden)	Carbon Tax (Sweden)
Climatop (Switzerland)	"Japan as a low carbon society" (Japan)

PAS 2050:2011

PAS 2050:2011 (BSI 2011), *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services,* was developed as an initiative sponsored by DEFRA and the UK Carbon Trust, was published through the British Standards Institution (BSI) in 2008 and revised in 2011 after extensive review. The objective of PAS 2050 was to enable industry users to apply LCA methodology to a wide range of products in a consistent manner. It focuses only on the GWP impact, i.e. the carbon footprint indicator. While PAS 2050 is based on the ISO 14000 series of standards and the two standards have many elements in common, there are differences which in general restrict the methodological choices for practitioners, i.e. in seeking greater consistency in application of the methods it became less generic.

The 2011 revision of PAS 2050 aimed to resolve some of the issues raised by users of the original release (e.g. concerning capital goods exclusion and setting materiality thresholds), and to better harmonise PAS 2050 with the WRI GHG Protocol and the emerging ISO 14067 methodologies. PAS 2050:2011 states that the assessment of the impact of land use change shall include all direct land use change occurring not more than 20 years, or a single harvest period, prior to undertaking the assessment (whichever is the longer). The total GHG emissions and removals arising from direct land use change over that period shall be included in the quantification of GHG emissions of products arising from this land on the bass of equal allocation to each year of the period.

In Australia, PlanetArk and the UK Carbon Trust have launched the Carbon Reduction Label program based on BSI PAS 2050:2011. To date ALDI, Dyson and the NZ Wine Company have had products labelled under the program. These types of labelling programs allow carbon related information to be displayed on products and services that can be taken into account in consumer purchasing decisions.

WRI/WBCSD GHG Protocol Product Standard

The GHG Protocol product standard from World Resources Institute & World Business Council for Sustainable Development (WRI/WBCSD) provides a framework for estimating the total GHG emissions associated with a product. Similar to PAS2050, it is based on an LCA approach and is also broadly consistent with the ISO TS 14067. It is not intended to support comparisons between products but WRI emphasises its use for analysis, tracking changes over time, developing options for reducing emissions and public reporting.

PAS 2050 and the GHG Protocol currently provide the most widely used ‘Carbon Footprint’ or GHG accounting guidance internationally. The objective of the GHG Protocol for publicly reporting of results as opposed to comparison of products is a key difference between the two standards.

ISO TS 14067

ISO TS 14067 specifies the principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product (CFP), based on International Standards on life cycle assessment (ISO 14040 and ISO 14044) and on environmental claims, labels and declarations (ISO 14020, ISO 14024, ISO 14025). It has significant differences to PAS 2050 and the WRI/WBCSD

GHG Protocol but follows many aspects of these and also work initiated in Japan on carbon labelling. However it must be emphasised that this single impact category of GWP (GHG emissions) is only one aspect of the impact of land use for agricultural production or other human activity and cannot be assumed to represent a ranking of the total environmental impact of different products. All widely used methodologies for LUC in LCA or product carbon footprint studies recommend that indirect LUC is excluded until a suitable methodology is developed.

Some differences between the most widely used international carbon footprint standards in the treatment of direct and indirect land use change are shown in Table 52. Table 52 simply demonstrates that the complexity of methodological difference requires attention to details of quantification.

Table 52 – Brief summary of methodological differences in the treatment of land use change between the three major international standards for assessing the carbon footprint of products.

	WRI GHG Protocol	ISO TS 14067	PAS 2050
Direct Land Use Change	Attributable land use change is required for inclusion; include all direct LUC occurring 20 years (or the length of 1 harvest for managed wood) prior to the time of harvest and 5% of total emissions in each year over a 20 year allocation period.	When significant, GHG emissions and removals occurring as a result of direct LUC shall be assessed in accordance with the goal and scope of the study and in accordance with Internationally recognized methods such as IPCC Guidelines for NGGIs.	The assessment of the impact of LUC shall include all direct LUC occurring on or after 1 Jan 1990 with 5% of total emissions included in each year over the 20 years following the change in land use.
Indirect Land Use Change	Not included	Indirect LUC shall be considered in CFP studies, once an internationally agreed procedure exists. All choices shall be justified and reported.	Not included

An important difference between standards is the time period for assessment of carbon emissions and removals for products. ISO TS 14067 states that, for all life cycle stages except the use stage and the end-of-life stage, GHG emissions and removals are to be included as if released or removed at the beginning of the assessment period. All GHG emissions and removals arising from the use stage or end-of-life stage are calculated as if occurring at the beginning of the assessment period and included in the CFP without the effect of timing of the GHG emissions and removals. However, where occurring over more than ten years from the product entering into use, the timing of GHG emissions and removals relative to the year of production of the product is also to be specified in the life cycle inventory, and the effect of this timing of the GHG emissions and removals from the product system (as CO_2-eq) may be included in the life cycle inventory and documented separately in the CFP study report.

There is also considerable debate over the extent to which biogenic carbon sequestration may represent a significant quantum of removal of atmospheric CO_2, predominantly by incorporation into soil organic matter. Confidence in significant soil organic carbon sequestration being achieved is highest for management changes from intensive cultivation to perennial pasture or forest cover. In ISO TS 14067[3], soil carbon change occurring due to Land Use Change impact assessment is included in the quantified carbon footprint. The draft standard states that if not calculated as part of LUC, the GHG emissions and removals occurring as a result of soil carbon change should be assessed and included in the life cycle inventory in accordance with internationally recognized methods such as the IPCC Guidelines for National Greenhouse Gas Inventories. It is then documented separately in the CFP study report.

[3] ISO TS 14067: In the absence of land use change and when significant, the GHG emissions and removals occurring as a result of soil carbon change should be assessed and reported separately Use internationally recognized methods such as the IPCC Guidelines for National Greenhouse Gas Inventories