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Prepared by: Dianne Mayberry, Harriet Bartlett, Jonathan Moss, Stephen Wiedemann, Mario Herrero
Commonwealth Scientific and Industrial Research Organisation

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Meat and Livestock Australia Limited
Locked Bag 1961
NORTH SYDNEY NSW 2059

Greenhouse Gas mitigation potential of the Australian red meat production and processing sectors

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Abstract

The aim of this project was to investigate pathways for the Australian red meat sector to become carbon neutral. First, baseline greenhouse gas (GHG) emissions were established for the sector for 2005. Emissions from livestock (beef cattle, sheep, goats), production of livestock feed (pastures, crops), land management, processing and energy use were included. We excluded emissions from dairy, wool, and live export of cattle and sheep. Emissions from the red meat sector in 2005 were 124.1 Mt CO_2e. The main sources of emissions were deforestation and enteric methane fermentation from grazing animals. The most promising mitigation options were identified, and a series of pathways to reduce GHG emissions evaluated. The study presents theoretical pathways for the Australian the red meat sector to substantially reduce emissions by 2030, and even become carbon neutral. Large reductions in GHG emissions can be achieved through land management (tree planting, savanna burning management, reduced deforestation), and reduction of enteric methane emissions from grazing animals (feed additives, vaccines, breeding, more efficient production). However, these pathways need to be further researched and developed, then supported with appropriate policy mechanisms and economic incentives.

Executive summary

The purpose of this project was to investigate if the Australian red meat industry could become carbon neutral by 2030 (CN30), and if so, how. This involved firstly establishing a greenhouse gas (GHG) emissions baseline year (2005) encompassing farm, feedlot and processing sectors. Following this, the most promising practices to reduce and offset GHG emissions were identified and a series of research, development and adoption (RD&A) pathways proposed.

In 2005, GHG emissions attributed to the red meat sector were 124.1 megatonnes of carbon dioxide equivalents (Mt CO_2e). This equated to 21% of national GHG emissions (Figure 1). Baseline emissions were calculated based on emissions reported in the Australian UNFCCC National GHG Inventory (Commonwealth of Australia 2017), with additional data sourced from the Australian Meat Processor Corporation (AMPC 2014, Ridoutt et al 2015) and life cycle assessment studies (Wiedemann et al 2015, 2016, 2017). Emissions from dairy cattle and wool production were excluded. Emissions from live export animals were not included once the animals left Australia.

The main sources of emissions from the red meat industry in 2005 were deforestation (permanent clearing of primary forest) and enteric fermentation in grazing cattle and sheep (Figure 1). Revegetation and conversion of grassland to forest were the major GHG sinks (Figure 2).

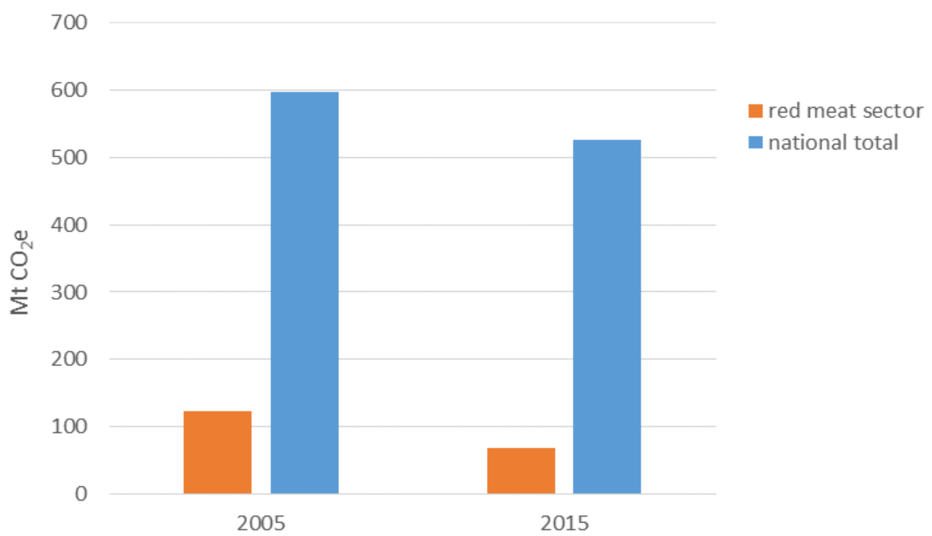

Figure E1. Greenhouse gas emissions from the red meat industry and total national emissions in 2005 and 2015.

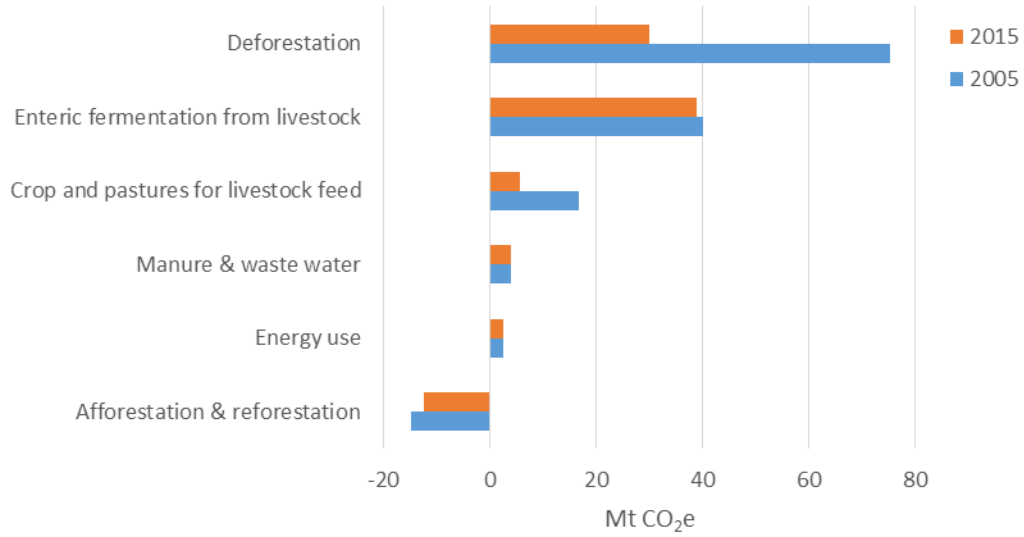

Figure E2. Breakdown of greenhouse gas emissions from the red meat sector.

The most promising GHG mitigation options identified were land management practice change (savanna burning management, reduced deforestation, sequestration of carbon in trees), feed additives and vaccines to reduce enteric methane fermentation (methane released from cattle, sheep and goats), and improved animal husbandry and management to increase production efficiency (reduced methane emissions per unit of meat produced). These practices were incorporated into the following pathways, which provide an indication of how the Australian red meat sector can reduce GHG emissions. The pathways were based on 25 million head beef cattle, 70 million sheep and 0.5 million goats. They were compared to a *Business as usual* scenario, where there was no change to current animal and land management practices.

1. *Vegetation management*. Permanent clearing of forest and conversion to grassland ceases. This pathway leaves 39.6 Mt CO_2e to be offset through carbon sequestration measures.
2. *Reduced enteric emissions in feedlots (feedlot futures)*. Increase in feedlot cattle numbers and decrease in enteric methane fermentation in feedlot cattle by 90% using feed additives. This pathway leaves 65.9 Mt CO_2e to be offset through carbon sequestration measures.
3. *Reduced enteric emissions in grazing (grazing futures) – low adoption*. In addition to the feedlot futures pathway, enteric methane fermentation is reduced by 40% in 10% of grazing sheep and beef cattle using a combination of feed additives, supplements, vaccination and feeding legumes. Zero conversion of forest land to grassland. Savanna burning management is used to reduce emissions from northern Australia. This pathway leaves 24.9 Mt CO_2e to be offset through carbon sequestration measures.
4. *Reduced enteric emissions in grazing (grazing futures) – high adoption*. This pathway is the same as the low adoption pathway, but assumes enteric methane is reduced by 40% in 40% of grazing sheep and beef cattle. This pathway leaves 20.7 Mt CO_2e to be offset through carbon sequestration measures.
5. *Beyond methane*. Methane emissions are reduced by 80% in 90% of grazing sheep and beef cattle, which would be possible if a methane vaccine and new delivery mechanisms to provide

feed additives to grazing livestock were available. There is also high feedlot numbers and decrease in feedlot cattle emissions, zero deforestation and increased savanna burning management. This pathway leaves 1.0 Mt CO_2e to be offset through C sequestration.

The theoretical GHG emissions savings from the pathways are shown in Figure 3. If the remaining emissions were offset with carbon sequestration through tree planting, it would be possible for the industry to become carbon neutral.

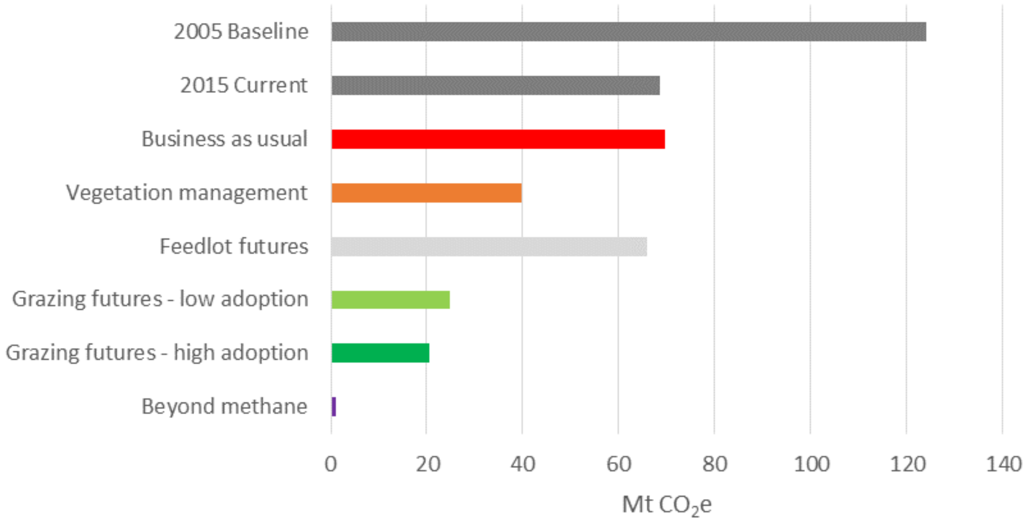

Figure E3. Greenhouse gas emissions from pathways to CN30 compared to 2005 baseline and 2015 (current) emissions.

While possible to achieve, substantial investment in the key areas outlined below would be required:

- **Reduced methane emissions from livestock -** Enteric fermentation of methane can be reduced through feed additives or supplements. However, industry requires new technologies and delivery mechanisms that are applicable to grazing livestock. Vaccines and improved genetics plus herd management may be more practical and more likely to be adopted.
- **Savanna burning management** - Controlled burning of savannas in the early dry season produces less GHG emissions than wildfires in the late dry season. Carbon prices will be a key driver of future uptake of this method.
- **Balancing permanent tree cover and feedbase** – this involves investigating methods of balancing permanent tree and pasture cover to sequester carbon, deliver a productive feedbase, and protect biodiversity. These methods will require policy support and economic incentives such as those provided through the Australian Government's Emissions Reduction Fund (ERF). In addition, integrated grazing and primary forest management practices should be considered to maximise productivity benefits.
- **Carbon sequestration** - using approved methods. This could include avoiding clearing and deforestation, reforestation, manage regrowth, human-induced regeneration, and soil carbon in grazing systems. Further research is required to refine existing methods and develop new methods to sequester carbon into plants and soils that are compatible with livestock production.

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1 Background

The red meat industry is important to Australia, with a value of AUD$16.3 billion (ABS 2017a), and employing around 200,000 people (MLA 2017c). Australia is one of the biggest producers of red meat in the world, producing 3% of the world's beef and 8% of lamb and mutton (MLA 2017c; MLA 2017d). Australia is the third largest exporter of beef and the largest exporter of sheep meat, with almost 70% of red meat produced exported to the US, Asia (mostly China, Japan, Korea) and the middle east (MLA 2017a; 2017b; 2017e).

The red meat industry also contributes to Australian greenhouse gas (GHG) emissions. While emissions from Agriculture are declining, they currently account for 13.1% of total Australian emissions (Commonwealth of Australia 2017d). A total of 72.6% of agricultural emissions are from enteric fermentation by ruminants (cattle, sheep and goats), many of which are associated with the red meat sector. The red meat sector also contributes to emissions reported under land use and land use change through conversion of primary forest to grasslands.

As part of the Paris Agreement, Australia (under the current Liberal/National Party government) has committed to a 26-28% reduction in GHG emissions by 2030 on a 2005 baseline (Commonwealth of Australia 2015b). This target will be reviewed every 5 years, and builds upon previous Australian Government commitments to reduce emissions by 5% between 2000 and 2020. The Australian Labour Party opposition has based its commitments on a reduction of at least 45% by 2030 on a 2005 baseline, and net zero emissions by 2050 (ALP 2017). State and Territory governments also have targets to become carbon neutral by 2050 (Government of South Australia 2015; ACT Government 2016; NSW Government 2016; Queensland Government 2017; Tasmanian Government 2017; Victoria State Government 2016).

The Emissions Reduction Fund (ERF) is a core component of the Australian Government policy in this area, and provides incentives for farmers and landholders to adopt new practices and technologies that reduce or avoid GHG emissions (Clean Energy Regulator 2016). Under the ERF, farmers participating in registered projects can earn Australian Carbon Credit Units (ACCUs), with each ACCU equivalent to 1 tonne of carbon dioxide equivalent (t CO_2e) saving in GHG emissions. These credits can be sold through auctions, with the average price over the first 5 auctions being AUD11.83/ACCU.

While the red meat industry has achieved substantial reductions in GHG emissions over the past 20 years (Wiedemann *et al.* 2015b), there is increasing pressure from consumers as well as government to further reduce the environmental footprint of red meat. It is important for Australia to continue to promote its clean, green, safe meat credentials on the global protein market. The Brazilian state of Mato Grosso do Sul has recently initiated a Carbon Neutral Beef initiative, which if successful, could increase competition with Australian exports. Alternatively, decreasing emissions from the red meat industry potentially allows Australia to maintain or increase both domestic and export market share, and increase prices for Australian product.

There has been much research into ways to decrease GHG emissions from various parts of the red meat industry. However, the industry lacks information on how various technologies and practices can be combined to reduce emissions from the whole sector. The overarching aim of this project was to investigate pathways for the Australian red meat sector to become carbon neutral by 2030.

2 Project objectives

The objectives of the project were to:

1. Establish an emissions baseline for the Australian red meat industry that is consistent with the national inventory. The project boundaries are the farm and meat processing sectors of the beef and sheep industries of Australia.
2. Identify and quantify the most promising GHG emissions mitigation and offset practices that are either available or likely to be available during the analytical time horizon.
3. Identify and quantify the impacts of the above practices that are likely to succeed based on applicability (i.e. how widely within the Australian red meat industry they can be applied), feasibility (i.e. how easily from a management perspective the practices can be applied) and cost effectiveness.
4. Identify a series of pathways or scenarios that would allow the industry to become carbon neutrality by 2030, exploring the policy options needed to incentivise practice uptake.

3 Methodology

3.1 Baseline emissions from the red meat industry

In keeping with Australia's commitments under the Paris Agreement, the year 2005 was set as the baseline year of emissions for the red meat industry. Emissions for the year 2015 were also calculated, using the most recent published data from the Australian United Nations Framework Convention on Climate Change (UNFCCC) inventory as an indication of current emissions (Commonwealth of Australia 2017a). The Australian UNFCCC National GHG inventory (hereafter referred to as "the inventory") reports GHG emissions as total CO_2e and amount of CO_2, methane and nitrous oxide for each sector. This study was restricted to Australia, therefore GHG emissions associated with export of live animals were not included once the animals were outside of the country.

Emissions associated with the red meat industry include emissions from livestock (enteric methane, manure), production of livestock feed (pastures, cropping), land management practices, meat processing and energy use (including transport). Emissions were primarily calculated based on values reported in the inventory (Commonwealth of Australia 2017a), and the Department of Environment and Energy provided access to detailed datasets not publicly available for download. Additional data on processing was sourced from the Australian Meat Processor Corporation and life cycle assessment studies commissioned by MLA (AMPC 2014; Ridoutt *et al.* 2015). Supplementary data on livestock numbers and commodities were obtained from the Australian Bureau of Statistics (ABS 2017c) and Australian Bureau of Agricultural and Resource Economics (ABARES 2017b). While the study did not employ a full 'life cycle' approach and thus omitted emissions from some components such as purchased inputs of fertiliser and feed, these impacts are relatively small and are described in detail elsewhere (e.g. Wiedemann *et al.* 2016; 2015a; 2015c).

Where possible, methods below are described using headings consistent with the current inventory. A detailed list of emissions categories and sub-categories used in this report are available in Appendix 9.2.

3.1.1 Emissions from livestock

The inventory reports emissions from livestock separately for beef feedlot, beef pasture, dairy cattle, sheep and goats. Dairy cattle were specifically excluded from this study wherever possible. Although some animals from the dairy sector are consumed as red meat, these were considered to be by-products of the dairy industry. All emissions from sheep were allocated to either meat or wool production based on the protein mass allocation method described by Wiedemann *et al.* (2015c), and using data on meat and wool production from the ABS (ABS 2017c). Although some emissions from goat production may be attributable to the dairy or fibre industries, inadequate data was available to allocate emissions to the other sectors, thus all emissions were allocated to red meat. However, total emissions from goat production are insignificant compared to beef cattle and sheep, and allocating emissions to different industries would have made almost no difference to the baseline.

3.1.1.1 *Enteric fermentation*

Enteric methane production is reported in the inventory for beef cattle feedlot, beef cattle pasture, sheep and goats (Section 3A). Details on how emissions from enteric fermentation are calculated are reported in Section 5.3 of the inventory (Commonwealth of Australia 2017d). Values for beef cattle and goats were reported directly from the inventory, and values for sheep meat production were corrected for meat-wool co-production as described above.

3.1.1.2 *Manure management*

Emissions from manure are reported in two different sections of the inventory. *Manure management* (section 3B) includes methane and nitrous oxide emissions from systems where large amounts of manure accumulate and manure is stored in piles or lagoons (e.g. feedlots). Methane is produced from anaerobic decomposition of manure, and nitrous oxide is produced from direct emissions and indirectly, via atmospheric deposition of nitrogen gases, leaching and runoff of nitrate. Details on how emissions from *Manure management* were calculated are reported in section 5.4 of the inventory (Commonwealth of Australia 2017d). Values were reported directly from the inventory, except for emissions from sheep, which were corrected for meat-wool co-production.

Nitrous oxide emissions from animal manure applied to soils as organic fertiliser (beef cattle feedlot) and urine and dung deposited by grazing livestock are reported under *Agricultural Soils* (section 3D.A.3).

3.1.2 Emissions from agricultural soils

Nitrous oxide emissions from *Agricultural soils* include direct emissions from animal waste applied to soils (feedlot cattle), urine and dung deposited by grazing animals (beef cattle pasture, sheep, goats), inorganic fertilisers, crop residues, mineralisation of soil carbon and cultivation of histosols. Indirect emissions (atmospheric deposition, nitrogen leaching and runoff) are also reported for manure, fertiliser, crop residues, and mineralisation due to loss of soil carbon.

Direct and indirect emissions from manure of beef cattle (pasture and feedlots) and goats were reported directly from the inventory. Emissions from sheep were corrected for meat/wool co-production.

Emissions from soils are reported for crops and pastures, and were attributed to the red meat industry as described below.

3.1.2.1 *Cropping*

Wiedemann *et al.* (2017) reported the area of crop land per kg liveweight gain for feedlot beef cattle. These values were used to estimate the area of crop land used to support the feedlot industry based on the number of feedlot animals, average days on feed, and average liveweight gain for domestic, export mid-fed and export long-fed cattle, using assumptions from the inventory calculations. The area of crop land used to provide feed for cattle was divided by the total crop land area reported in the inventory to calculate the proportion of emissions from cropping activities that could be attributed to the red meat industry (Table 1). This proportion was applied to all cropping emissions from agricultural soils.

Table 1. Values used to calculate proportion of crop land emissions associated with the red meat sector

Year	Area cropping land to support feedlots (million ha)	Total area crop land (million ha)	Crop emissions attributable to feedlot cattle (%)
2005	1.20	35.9	3.4
2015	2.08	36.2	5.7

3.1.2.2 *Pastures*

The inventory reports nitrous oxide emissions from irrigated and non-irrigated pastures. The ABS reports area of irrigated pasture for dairy, "meat cattle" and "sheep and other livestock" (ABS 2017b). The proportion of irrigated pasture emissions allocated to red meat was calculated as the proportion of irrigated land used for meat cattle and sheep production. The area of irrigated land for sheep and other livestock was unable to be disaggregated, but was corrected for co-production of meat and wool.

All emissions associated with non-irrigated pastures were included. While this likely overestimates emissions from non-irrigated pastures because it includes some grazing for dairy cattle and wool sheep, insufficient information was available to separate the industries.

3.1.3 Field burning of agricultural residues

Methane, nitrous oxide, CO, oxides of nitrogen and non-methane volatile organic compounds (NMVOCs) are produced from field burning of crop stubbles and other residues. Total emissions from field burning of residues were reported directly from the inventory (section 3F) and multiplied by the proportion in Table 1 to account for the fraction of cropland used to provide feed to beef cattle in feedlots.

3.1.4 Liming and urea application

Application of lime or dolomite to agricultural soils produces CO_2 as carbonates react with acids in the soil. Adding urea to soils as fertiliser leads to loss of CO_2 that was fixed during the manufacturing process. The inventory reports on total emissions from application of lime/dolomite and urea for the whole agricultural sector. Commodities data from the ABS (ABS 2014) were used to calculate the proportion of lime/dolomite and urea that was used by the red meat sector, and these proportions were applied to the total value reported in the inventory to calculate emissions associated with red meat. The ABS data included lime/dolomite and urea applied for livestock and crop production. Emissions for sheep production were corrected for meat/wool co-production. Emissions from cropping were allocated using the proportion of emissions from crop land reported in Table 1. ABS data on lime and urea use was only available for 2011-12, and the proportion of emissions allocated to the red meat sector was used for both 2005 and 2015.

3.1.5 Processing

Emissions from the processing sector come from wastewater, waste disposal, consumption of fuel and electricity (AMPC 2014). Average emissions (kg CO_2e/t hot standard carcass weight (HSCW)) from the processing sector are reported by AMPC for 2003, 2008-09 and 2015 (GHD 2011; Ridoutt *et al.* 2015). Since no information was available on emissions in 2005, the average value of 2003 (525 kg CO_2e/t HSCW) and 2008 (554 kg CO_2e/t HSCW) emissions was used (Table 2). Average emissions were multiplied by the volume of sheep meat and beef produced for human consumption in each year (ABS 2017c). Sheep meat included both lamb and mutton. Beef produced excluded calves, but included an unknown number of cull cows from the dairy industry. Calves were removed from the analysis as it was assumed the majority of these were by-products of the dairy industry. Statistics on the number and weight of dairy cows slaughtered were not available, so they were unable to be removed from the analysis.

Table 2. Assumptions used in calculating emissions from the red meat processing sector. Processing emissions are reported in Ridoutt et al. (2015). Meat production is from the ABS.

	2005	**2015**
Average processing emissions (kg CO_2e/t HSCW)	540	432
Total sheep meat production (kt HSCW)	615.9	710.5
Total beef production (kt HSCW)	2,062.5	2,513.9

3.1.6 Energy use – feedlots and on-farm

Major sources of energy use in the red meat industry include feed processing, vehicle and machinery operation (e.g. pen cleaning, feed delivery) and transport of livestock, inputs and staff.

Feedlots

GHG emissions from energy usage in feedlots were calculated based on amount of energy consumed (Wiedemann *et al.* 2017), energy content and emissions factors for electricity, diesel, gas and petrol reported by the National Greenhouse and Energy Reporting Scheme (Commonwealth of Australia 2017f), and the number of feedlot cattle, days spent on feed and total intake (using numbers from the inventory).

On-farm

GHG emissions from beef and sheep production were calculated based on the energy usage reported by Wiedemann *et al.* (2016) and Wiedemann *et al.* (2015c). Emissions from energy associated with beef production were calculated based on dry matter intake of cattle, and emissions from sheep were calculated based on number of ewes joined. These calculations were based on the inventory assumptions of feed intake and number of breeding ewes.

3.1.7 Land use, land use change and forestry

The inventory reports on emissions from forest land, crop land, grasslands, wetlands and settlements at the national level. Emissions from wetlands and settlements were not attributable to the red meat industry.

3.1.7.1 *Forest land*

Forests include all vegetation with a tree height of at least 2 m and crown canopy cover of at least 20% (Commonwealth of Australia 2017e). This category includes forest areas where livestock graze, as well as conservation forests and plantations. The major source of GHG emissions from forest land are from temporary loss of woody vegetation and biomass burning (controlled burning and wild fires). Permanent losses of woody vegetation (deforestation) are reported under *forest land converted to grassland* and *forest land converted to crop land*. Methods for calculating total emissions from forest land are reported in section 6.4 and 6.5 of the inventory (Commonwealth of Australia 2017e).

Forest land remaining forest land

GHG emissions from *forest land remaining forest land* are reported for harvested native forests, plantations, other native forests and fuelwood (Commonwealth of Australia 2017e). Grazing mostly occurs on other native forests. However, this category also includes protected areas such as national parks. The total area of other native forests used in the inventory is 123.6 M ha. ABARES reports that 39.2 M ha of native forests are protected for biodiversity and conservation (ABARES 2017b), so we assume that the remaining 84.4 M ha or 68% of other native forests are available for grazing. GHG emissions from other native forests were multiplied by 0.68 to provide an estimate of the amount of emissions attributable to the red meat industry.

Land converted to forest land

This category covers increases in woody vegetation, including plantations and regeneration of forest from natural seed sources.

Emissions from *grassland converted to forestland* (afforestation and reforestation) were assumed to be associated with grazing industries. Data were not available to divide this into emissions associated with beef, sheep and dairy. Since the majority of land converted to forest land occurred in northern Australia, which is dominated by the beef industry, it was assumed that all emissions associated with conversion of grasslands to forest land were associated with the red meat industry. Values were reported directly from the inventory.

Emissions from *wetland converted to forest land* were excluded.

3.1.7.2 *Cropland*

Cropland includes land used for continuous cropping and crop-pasture rotations. Anthropogenic emissions and removals on croplands are caused by changes in management practices, crop type and land use. Methods for calculating emissions are described in section 6.6 and 6.7 of the inventory (Commonwealth of Australia 2017e). Emissions from cropland were allocated to the red meat industry by multiplying total emissions from *cropland remaining cropland* and *forest land converted to cropland* by the proportion in Table 1.

3.1.7.3 *Grassland*

Grasslands include improved pastures, native grasslands, shrublands and other woody vegetation not dense enough to be considered forest. Emissions relate primarily to changes in land management practices such as fire management, and changes in woody vegetation cover caused by changing climate, fire and clearing. Methods for calculating emissions are described in section 6.8 and 6.9 of the inventory (Commonwealth of Australia 2017e).

Grassland remaining grassland

Allocation of grassland emissions to the red meat sector was calculated based on proportion of pasture used by different livestock, using animal intake as a proxy. Total dry matter intake of beef cattle pasture, dairy cattle and sheep was calculated using unpublished data provided by the Department of the Environment and Energy and used in their estimates of GHG emissions from livestock. Grain/concentrate and silage/hay intake of dairy cattle was subtracted from total dairy cattle intake using data provided by Dairy Australia (Peter Johnson *pers comm*). Total sheep intake was corrected for meat/wool co-production. The sum of beef cattle pasture and sheep meat intake divided by total intake from grasslands (beef cattle pasture, sheep, dairy cattle – grain) was taken as the proportion of emissions from *grassland remaining grassland* associated with the red meat sector.

Forest land converted to grassland

This section of the inventory covers permanent losses of forest land and conversion to grassland (Commonwealth of Australia 2017e). Temporary losses of woody vegetation characterised as forests are reported under *forest land remaining forest land*. Temporary losses of woody vegetation not classified as forests and shrubland transitions are accounted for under *grassland remaining grassland*. Losses are monitored over time to determine if they are permanent or temporary.

All emissions associated with conversion of forest to grasslands were allocated to the red meat industry since land clearing occurs primarily in northern Australia (Commonwealth of Australia 2017a).

3.2 Mitigation options

The mitigation options explored fall into two broad categories: 1) practices that directly reduce GHG emissions from the red meat industry, and 2) practices that result in the sequestration of carbon either in woody vegetation or grazing land soils.

3.2.1 Prioritising mitigation options

A two-stage Delphi survey of experts was conducted to identify the most promising mitigation options for the Australian red meat industry. The survey was reviewed and approved by the CSIRO Social Science Human Research Ethics Committee. The first round of the survey was sent to 49 participants, with 38 completed. 28 responded to the second round of the survey. Participants were invited from a range of different sectors and relevant scientific research areas around Australia including livestock production systems, animal nutrition, livestock genetics, rangeland management, forestry, savanna burning and fire management, soils, agribusiness, life cycle assessment, meat processing, and carbon farming consultants.

In the first round of the survey, participants were presented with different mitigation options described by Hristov *et al.* (2013), AMPC (2014), Herrero *et al.* (2016) and Smith *et al.* (2008) (Table 3). Participants were asked to choose and rank the 10 options that they thought were most important to reduce emissions from the Australian red meat sector. They were also able to add additional options. Participants were then asked a series of questions to identify;

- which production systems these options were applicable to (all beef and sheep, all feedlot beef, southern pasture beef, northern pasture beef, or all sheep)
- when these options would be available to industry (now, 1-3 years, 3-5 years, 5-10 years, > 10 years)
- the scale of mitigation potential
- the practical feasibility (changes to production system)
- the economic feasibility

Table 3. List of mitigation options presented in Delphi survey (AMPC 2014; Herrero et al. 2016; Hristov et al. 2013; Smith et al. 2008). The 'other' categories includes suggestions from survey participants.

Category	Mitigation options
Enteric fermentation	Feed additives • inhibitors • electron receptors • ionophores • plant bioactive compounds • dietary lipids • exogenous enzymes • direct-fed microbials Defaunation Vaccines Feeds & feeding management • concentrate inclusion • forage quality and management • precision feeding • filling feed gaps
Animal husbandry	Enhancing animal productivity • animal genetics • reduced age at harvest and days on feed • hormonal growth promotants Animal fertility • mating strategies to improve fertility • enhanced fecundity • reduction of stressors • assisted reproductive technology • peri-parturient health improvement
Soil C sequestration	Grazing management • change in pasture species/inclusion of legume • optimising stocking rates • rest periods
Land use	Reforestation Savanna burning management Reduced deforestation Woody biomass growth
Processing	Biogas and cogeneration Using biogas as boiler fuel Covering anaerobic lagoons Improving refrigeration technologies Anaerobic digesters Treatment of biogas
Manure management	Anaerobic digesters

	Urease, methanogen and nitrification inhibitors Control of manure emissions through grazing practices Composting Manure storage and separation Manure storage covers Cover cropping
Other	Purchasing carbon offsets Alternative energy sources Reduce transport emissions

These results were then collated to create a ranked list of mitigation options based on the opinions of all experts. This list and a summary of the production systems, timing, scale and feasibility of the top options was presented to participants in the second round of the survey. Participants were asked to reflect on the results and if they agreed or disagreed with our summary.

3.2.2 Pathways to CN30

Pathways to carbon neutrality in 2030 (CN30) were developed in consultation with MLA and compared to a *Business as usual* scenario. The pathways were designed to target the major sources of GHG emissions from the red meat sector and incorporated the most promising mitigation options identified in the Delphi survey. Key components of the pathways were;

- Reduction in enteric methane fermentation in ruminants
- Reduced deforestation (permanent clearing of primary forest)
- Improved savanna burning management

The pathways are briefly described in Table 4, with details on assumptions and methods provided below. Assumptions were based on a combination of industry trends, published literature and expert opinion.

Table 4. A summary of assumptions underpinning modelled pathways

	Business as usual	Vegetation management	Feedlot futures	Grazing futures – low adoption	Grazing futures – high adoption	Beyond methane
Total livestock numbers						
Beef cattle (million head)	25	25	25	25	25	25
Sheep (million head)	70	70	70	70	70	70
Goats (million head)	0.5	0.5	0.5	0.5	0.5	0.5
Number feedlot cattle						
Number cattle (million head)	2.8	2.8	5.6	5.6	5.6	5.6
Annual equivalent (million head)[A]	0.93	0.93	1.85	1.85	1.85	1.85
Reduction in enteric methane						
Beef cattle - feedlot	None	None	By 90% in all feedlot cattle	By 90% in all feedlot cattle	By 90% in all feedlot cattle	By 90% in all feedlot cattle
Beef cattle and sheep - pasture	None	None	None	By 40% in 10% grazing animals	By 40% in 40% grazing animals	By 80% in 90% grazing animals
Land use and land use change						
Savanna burning management (45 M ha)	No	No	No	Yes	Yes	Yes
Zero deforestation	No	Yes	No	Yes	Yes	Yes
Carbon sequestration to offset remaining emissions	Yes	Yes	Yes	Yes	Yes	Yes

[A] annual equivalent numbers = number of cattle in feedlots corrected for days on feed

3.2.2.1 *Business as usual*

This pathway is designed to highlight what happens if the red meat industry does not actively seek to reduce greenhouse gas emissions. The beef cattle herd increases from 24 million cattle in 2015 to 25 million cattle in 2030 (current 10 year average). Sheep and goat numbers stay steady at 70 million sheep and 0.5 million goats.

In this pathway there is no research and development investment in reducing emissions, so there are no changes to emissions from livestock on a per head basis. Emissions from enteric fermentation, manure, processing and transport are increased based on the total number of cattle. Deforestation remains at 2015 levels.

3.2.2.2 *Vegetation management*

Deforestation is a major source of GHG emissions. Reductions in land clearing have primarily been driven by policies restricting permanent conversion of primary forest. Land clearing in Australia has decreased from 591,000 ha of primary forest in 1990 to just 56,000 ha in 2015 (Commonwealth of Australia 2017c). Emissions from this sector include an immediate loss of carbon as trees are cleared, followed by on-going loss of soil carbon before it reaches a new equilibrium (Commonwealth of Australia 2017e). This pathway assumes that deforestation ceases within the next 5 years, and that soil carbon stocks have stabilised by 2030. i.e. there are no emissions associated with deforestation in 2030.

3.2.2.3 *Feedlot futures*

The number of cattle in feedlots has been steadily increasing from 750,000 head in 1990 (3.4% of total) to 2.8 million in 2015 (12% of total) (Commonwealth of Australia 2017b). Increasing the number of cattle finished in feedlots reduces GHG emissions by decreasing the number of grass-fed cattle, reducing age at slaughter, and increasing weight at slaughter. Wiedemann *et al.* (2015b) reported that between 1990 and 2010 the average age of steers at processing decreased from 2.34 to 2.18 years, average liveweight at processing increased from 538 to 574 kg, and average liveweight gain of steers between birth and processing increased from 0.55 to 0.72 kg/head/day. These changes were attributed primarily to an increase in the number of grain-fed and feedlot finished cattle.

In this pathway, the total cattle numbers increase to 25 million as per the *Business As Usual* pathway, and the number of animals entering feedlots is doubled to 5.6 million in 2030. The number of feedlot cattle is increased uniformly across domestic, export long-fed and export medium-fed categories. The annual equivalent number of cattle in feedlots (number of animals corrected for days on feed) is thus increased from 0.93 to 1.85 million. Increasing the number of animals in feedlots decreases the size of the total cattle herd since animals are slaughtered earlier. The adjusted cattle herd was calculated to be 23.6 million head.

An increase in feedlot cattle numbers necessitates an increase in the proportion of cropland needed to support feedlot cattle. The proportion of cropland needed to support feedlot cattle (Table 1) is increased to 0.12 based on new feedlot cattle numbers.

Mitigation options in this pathway target enteric methane fermentation, which is the main source of emissions. Substantial and sustained reductions (up to 93%) in enteric methane have been measured in feedlot cattle fed grain-based diets containing small amounts of bromochloromethane (BCM)

(Tomkins *et al.* 2009). While the manufacture and use of BCM in Australia and other countries has been banned, there may be other compounds with similar modes of action, and there is still potential for discovery of new inhibitors (Henderson *et al.* 2016). Natural feed additives such as red algae (*Asparagopsis taxiformis*) have shown reductions of similar scale in sheep and cattle in *in vitro* experiments (Kinley *et al.* 2016; Li *et al.* 2016; Machado *et al.* 2016). Experts in this area agree that inhibitors that almost eliminate enteric methane fermentation in feedlot cattle fed grain-based diets will be available by 2030 (John Black, Chris McSweeney *pers comm*). In this pathway, it is assumed that through provision of feed additives, enteric methane production by feedlot animals can be reduced by 90%.

There is no change to management of grazing livestock or levels of deforestation in this pathway.

3.2.2.4 *Grazing futures - low adoption*

Most livestock in Australia graze pastures rather than being fed in feedlots, so options to reduce GHG emissions from pasture-based systems are required. In addition to practices outlined in the *feedlot futures* pathway, this pathway includes decreased methane emissions from grazing cattle and sheep, emissions abatement through Savanna burning management, and zero deforestation.

The most promising options to decrease enteric methane emissions from grazing livestock include vaccination against methanogens (5-20% reduction in methane), genetic selection and breeding of low methane emitting animals (up to 15% decrease in methane), and feeding of legumes, which can decrease methane emissions through the action of secondary compounds and improved feed conversion efficiency (up to 20% reduction in methane) (Buddle *et al.* 2011; Eckard *et al.* 2010; Harrison *et al.* 2015; Hristov *et al.* 2013). Combined, these methods could reduce enteric methane emissions by 40% (Chris McSweeney, John Black *pers comm*). In this pathway we assumed that these management practices would be applied to 10% of grazing beef cattle and sheep. Goats are not targeted since it is assumed that most are wild-harvested feral animals.

Savanna burning management can be used to reduce emissions from wildfire in northern Savannas, and is already included in the Emissions Reduction Fund (ERF). Controlled fires at the start of the dry season are less intense and release less methane and nitrous oxide compared to wildfires that occur late in the dry season (Maraseni *et al.* 2016). The average reduction in emissions from Savanna burning management was calculated based on current ERF projects, and was estimated to be 0.044 t CO_2e/ha/year for pastoral properties with Savanna burning management. Controlled, less intense burning also results in higher amounts of C being sequestered in living woody biomass (Murphy *et al.* 2010). The value of this is estimated to be approximately five times that from emissions avoidance, 0.22 t CO_2e/ha/year (Russell-Smith *et al.* 2015b).

Heckbert *et al.* (2012) estimate that at \$23/t CO_2e, Savanna burning projects are economically viable on 51 M ha of land in northern Australia. Given that 90% of northern Savannas are used for pastoral production (Russell-Smith and Whitehead 2015), in this pathway it is assumed that Savanna burning management could be practiced on 45 M ha in 2030. In 2015, almost 10 M ha of pastoral land in northern Australia had savanna burning projects under the ERF, so a reduction in GHG emissions for an additional 35 M ha of burning management was calculated.

This pathway also assume zero deforestation.

3.2.2.5 *Grazing futures – high adoption*

This pathway is the same as the *Grazing futures - low adoption* pathway, but assumes higher rates of adoption for enteric methane mitigations in the grazing herd. In this pathway, it is assumed that the use of vaccines, breeding and legumes to reduce methane emissions are applied to 40% of grazing cattle and sheep.

As with the *Grazing futures – low adoption* pathway, this pathway assumes high feedlot numbers, reduced methane from feedlots, savanna burning management and zero deforestation.

3.2.2.6 *Beyond methane*

This is a disruptive pathway designed to show the impact of a large number of changes to the red meat industry. A suite of changes including a methane vaccine and new delivery mechanisms to provide feed additives to grazing livestock enable methane emissions in grazing beef cattle and sheep to be reduced by 80% in 90% of animals.

In addition, this pathway assumes high feedlot numbers, reduced methane from feedlots, savanna burning management and no deforestation.

3.2.2.7 *Offsetting remaining emissions*

The area of tree planting required to offset remaining emissions was calculated for each pathway. Annual C sequestration by trees and shrubs varies substantially depending on location, type of tree, age of tree, tree management and many other factors. Henry *et al.* (2015) estimated the value of C sequestration by trees and shrubs to be between 0.7 and 5 t CO_2e/ha/year for different parts of southern Australia, while Polglase *et al.* (2008) reported a higher average sequestration potential of 7.4 t CO_2e/ha. Thus, the area of trees required to offset emissions from each pathway was calculated for a range of sequestration rates between 0.5 and 8 t CO_2e/ha.

The potential carbon sequestration from dung beetles, which can bury dung for carbon sequestration, was also estimated. While this is a novel method that has not yet been developed as a carbon sequestration method, it presents a real opportunity because of the high potential for adoption by producers. It was assumed that 70% of cattle and 50% of sheep are associated with productive dung beetles colonies, that 50% of dung is buried, and that 30% of buried carbon in dung is sequestered (Piccini *et al.* 2017). Calculations were based on the amount of dung production estimated by the inventory and assumed that the carbon content of diets grazed by ruminants was 45%.

3.2.3 Cost of CN30

For each of the pathways, economic analyses were conducted on each of the potential practices to reduce emissions. Economic modelling involved projecting the identification of all additional operating costs and benefits and any required capital investments associated with the practices to red meat producers between 2018 and 2030. Estimates of costs and benefits were derived from a range of sources and, where uncertainty existed, estimates provided by Government departments and industry experts were applied. The economic analyses were conducted with a focus on the costs to red meat producers and do not include any additional costs associated with the development and commercialisation of products and/or practices to reduce emissions.

Marginal abatement costs were the economic indicators estimated for each practice .This required the estimation of all cash flows and capital expenditure that differed from the business-as-usual case along with any estimated productivity improvements, their impact on the profit and emissions reduction. Discounted cash-flow modelling was undertaken for practices that have a project life greater than one year or where it was assumed that incremental adoption up to 2030 would occur . This allowed the net present value (NPV) of the different practices to be determined .The NPVs for the different practices were then converted into annualised present values for 2030 to allow comparison between the practices with different project lives .A discount rate of 7% was assumed in the calculation of NPVs, which is considered an appropriate rate for agricultural producers.

Quantities of abatement that could occur at different carbon prices were also modelled .While the average price of the first five ERF auctions between April 2015 and April 2017 was $11.83 per tonne of CO_2e, there is still considerable uncertainty surrounding the future price of carbon .The quantity of abatement that could be achieved at the average ERF auction price was estimated. However, lack of familiarity with emissions trading schemes, inability to access auction funds, or the lack of accepted methodologies for acceptance of all the practices may mean that not all producers and practices will operate under an emissions trading scheme. To account for this risk, a case where a carbon price of $0 per tonne CO_2e was also considered .The case for an optimistic increase in price up to $50 per tonne of CO_2e was also estimated.

The economic analysis is based on several assumptions which can have a significant influence on the viability of the different abatement practices. Assumptions on the implementation costs, years until implementation and productivity gain are presented in the section 3.2.3.3 'Practices Modelled'.

3.2.3.1 *Capturing Heterogeneity*

There is a high degree of variability in the production efficiency, operating costs, area operated and price received by livestock producers, even from similar regions (Martin 2016) .More efficient producers might be able to adopt abatement practices at a lower cost .Utilising a model that only presents the economic data and abatement costs based on representative farms for a region may not adequately capture the existing heterogeneity .To model this heterogeneity, a population of stochastic farms was simulated numerically using the MATLAB computing software (Mathworks 2017). This simulated a population of cattle, sheep and mixed farms of different size, with varying production efficiencies and operating costs .These populations of simulated farms were calibrated to historical data from the AgSURF database (ABARES 2017a) .

The modelled benefits and costs of each practice along with the emissions reduction analysis were then combined to construct marginal abatement cost curves for each of the pathways .

3.2.3.2 *Marginal Abatement Cost Curves*

The compilation of marginal abatement costs of each pathway, in ascending order as curves, allows visual identification of the quantity of abatement that can be achieved at different costs. When applied to the average marginal abatement costs for each practice, the marginal abatement cost curves (MACCs) are presented as a number of bars representing each individual practice .The height of each bar represents the average cost of abating a tonne of CO_2e from a given practice .Widths of the bars vary according to the total amount of abatement (Mt CO_2e) that can be achieved if the practice is implemented. When considered against different market prices for carbon, this methodology provides a visual reference to the quantity of abatement that can be achieved at these prices .All practices which fall below a given market price would reduce CO_2e emissions and increase the profitability of producers .Conversely, all practices with a marginal abatement cost greater than a given market price, while reducing emissions, would incur a cost on producers .

In addition to constructing MACCs based on average practice costs and emission reductions, further MACCs can be produced from the output of the heterogeneous model described above. The areas under the curves represent the total cost of achieving neutrality .While these curves do not provide quick identification of the individual lowest average-cost practices, as is possible when an average representative price for each practice is assumed, they do provide a more realistic estimation of the quantity of emissions that could be abated at different costs by capturing the often-varied costs of implementation .

3.2.3.3 *Practices Modelled*

For each of the pathways numerous activities were modelled to determine the economic feasibility . Some practices were not mutually exclusive and their combined abatement potential was not additive .In these cases, only the lowest-cost practices were included in the full economic analysis . The practices included in the pathways and their assumptions of costs, timing and productivity gain are discussed below.

3.2.3.3.1 Reducing enteric fermentation

Vaccinations

It is assumed that a vaccine to reduce methane emissions will be commercially available and implemented by 2028. Productivity was assumed to remain unchanged in vaccinated livestock. Vaccines are assumed to be a single-dose annual injection at a cost of $4.50 per head for cattle and $2.00 per sheep (Cotter *et al.* 2015).

Genetic improvement

Genetic improvement is assumed to occur naturally through time for producers using systems such as BREEDPLAN (ABRI n.d.) and LAMBPLAN (SGA 2008), which incorporate emissions reductions. A 5.2% reduction in emissions by 2030 (0.4% reduction per year) was assumed for producers adopting this practice (MLA 2015a). These small incremental improvements are not assumed to incur any additional cost to producers using these systems as the cost of selecting livestock based on the genetic trait of lower methane emissions is not considered to fundamentally differ from the selection of stock based on other desirable traits (Cotter *et al.* 2015).

Feed supplements

Feed supplements for feedlot animals were based on the assumption that a supplement to reduce methane emissions will become commercially available at an annual cost of $54.75 per head and $10.95 per sheep (Cotter *et al.* 2015) .It was assumed that these supplements will become available for implementation within five years and will provide a 5% productivity gain .

As part of the *Beyond methane* pathway, it was also assumed that an annual slow release supplement can be developed within 10 years that will reduce enteric methane emissions .An annual cost of $18 per head and $4.50 per sheep was assumed along with a 5% gain in productivity (MLA 2015a) .

Planting legumes

The establishment of new pasture legume species, such as Tedera (Real *et al.* 2014), were assumed to become commercially available in 2019. The re-introduction of legume species that were previously introduced into Australia in the 1970s, such as *Desmanthus sp*. (Vandermeulen *et al*. 2015), were also assumed to become commercially available by 2025. A total of 51 M ha in northern Australia and a further 18 M ha in southern Australia were assumed to be suitable for new legumes (based on discussions with Gavin Peck (QDAF) and Lindsay Bell (CSIRO)) .The area planted was based on the adoption rate of the modelled pathways and was assumed to increase linearly up to maximum area suitable multiplied by the adoption rate by 2030A method allowing inclusion of . emissions reductions from this practice under an ERF is assumed to beome available by2021 . Establishment costs were assumed to range between $250 and $400 per hectare with an average of $350 per hectare (NSW DPI 2017) .An annual maintenance cost of $62.50 per hectare was also assumed which is also comprised of an annualised cost of periodic re-sowing of legume crops to maintain productivity (NSW DPI 2017) .Productivity gains of 25% were assumed for the areas planted to new legumes.

3.2.3.3.2 Avoided emissions from vegetation management

Avoided deforestation

It was assumed that most of the avoided deforestation would occur in Queensland since that is where most deforestation currently occurs. The cost of avoided deforestation was estimated as the opportunity cost of the livestock which could have been run on this land if these forested areas were converted to grassland. It was also assumed that this area would need to remain forested for 100 years.

Savanna burning management

The implementation of savanna burning management practices was assumed to increase linearly from the 9.4 million hectares already included under the ERF in 2015 to 45 million hectares between 2018 and 2030. A productivity gain of 5% was assumed for this practice through the stimulation of 'green pick' and control of weeds (MLA 2015b). Management costs of $50.84 per square kilometre (Maraseni *et al.* 2016) were assumed .

3.2.3.3.3 Carbon sequestration

Tree regrowth

It was assumed that 2 million hectares of marginal country in western Queensland could be temporarily fenced to exclude stock for a period of three years while vegetation is allowed to re-grow. Fencing costs were assumed to range between $220 and $430 per hectare with an average cost of $245 (Queensland Government 2016c) .This practice is not expected to increase productivity on the rest of the farm .

Planting of trees and saltbush

Cost of establishing a hectare of trees was assumed to range between $1,500 and $3,350, with an average of cost of $2,230 (Polglase et al. 2013). Post-establishment costs per hectare ranged between $84 and $294 in the year after planting, with an average of $167 per hectare. The annual management costs of tree plantings were assumed to range between $11 and $84 per hectare, with an average cost of $33 per hectare (Polglase et al. 2013). The opportunity cost of the land foregone due to planting trees is also included when determining the cost of planting trees. No more than 5% of any farm was assumed to be planted to trees. A 10% productivity gain to the remainder of the farm from the benefits of shade provision (Gene Wijffels *pers comm*), with benefits assumed to begin five years after planting was assumed. An average annual sequestration rate of 3.5 t CO_2e per hectare was assumed for the economic analysis based on the range of sequestration rates reported by Henry et al (2015) and average values in the 2015 inventory (Commonwealth of Australia 2017a). Linear adoption of the required area of trees (Figure 7) was assumed to occur between 2018 and 2025. Undertaking the planting of the last additional areas required to achieve carbon neutrality in 2025 was assumed to allow these last areas planted enough time to establish. This ensures that the average projected sequestration rate per hectare by 2030 is achieved.

An area of 5.7 million hectares was assumed to be suitable to the planting of saltbush (Walden et al. 2017). Cost of establishment was assumed to range between $227 and $595 per hectare with a mean cost of $550 per hectare (CWCMA 2010). An average annual sequestration rate of 1.46 t CO_2e/ha (Walden et al. 2017) was assumed for areas planted to saltbush.

Dung beetles

It was assumed that 40% of the cattle herd and 5% of the sheep flock already have active dung beetle populations, and that a maximum of 70% of the grazing cattle herd and 50% of the grazing sheep flock could be covered by active dung beetle populations by 2030 (John Black *pers comm*). Cost of establishment was assumed at an average of $432, with a range between $340 to $541 for a mixed-species starter colony of active dung beetles that are sufficient for 50 head of cattle or 500 head of sheep. Values were based on those reported by Spence (2007) and adjusted to 2017 values after discussion with Nigel Andrew (UNE) and John Feehan (Dung beetle consultant) .It is assumed that appropriate species mixes will be available within five years and it will take six years from introduction of the starter colony for full benefit to be realised.

4 Results

4.1 Baseline and current emissions

In 2005, GHG emissions attributable to the Australian red meat industry totalled 124.1 Mt CO_2e (Table 5). This is equivalent to approximately 21% of national GHG emissions (Figure 1). In 2015, emissions from the red meat sector decreased by 45% to 68.6 million Mt CO_2e and 13% of national emissions. The decrease in emissions between 2005 and 2015 was largely due to a decrease in emissions from forest land converted to grassland (deforestation). Between 2005 and 2015 beef cattle numbers remained stable at 24-25 million head, but sheep numbers decreased from 100 to 70 million animals.

Table 5. Greenhouse gas emissions from the red meat sector for 2005 (baseline) and 2015 (current). Values are in Mt CO_2 equivalents. Categories are ranked from highest to lowest emissions in 2005 baseline year. A more detailed breakdown of baseline emissions is available in the Appendix section 9.2.

Category	Description	2005	2015
Grassland	Deforestation Changes in pasture, grazing and fire management	86.1	32.4
Enteric fermentation	Enteric methane from beef cattle pasture, beef cattle feedlot, sheep meat and goats	40.1	38.9
Agricultural soils	Application of fertilisers Urine and dung from grazing animals Crop residues Mineralisation of soil C Cultivation of histosols Atmospheric deposition N leaching and runoff	5.54	5.72
Processing	Emissions from waste, fuel and electricity associated with processing red meat	1.45	1.39
Energy use	Energy use on farm and in feedlots	1.40	1.39
Manure management	Anaerobic decomposition of manure	0.75	0.84
Liming and urea	Application of lime, dolomite and urea to soils	0.44	0.56
Cropland	Changes in management practices, crop type and land use	0.21	-0.03
Field burning ag residues	Field burning of crop stubbles and other residues	0.01	0.02
Forest land	Prescribed burning and wildfires Afforestation and revegetation	-11.83	-12.51
Total red meat sector		**124.1**	**68.6**

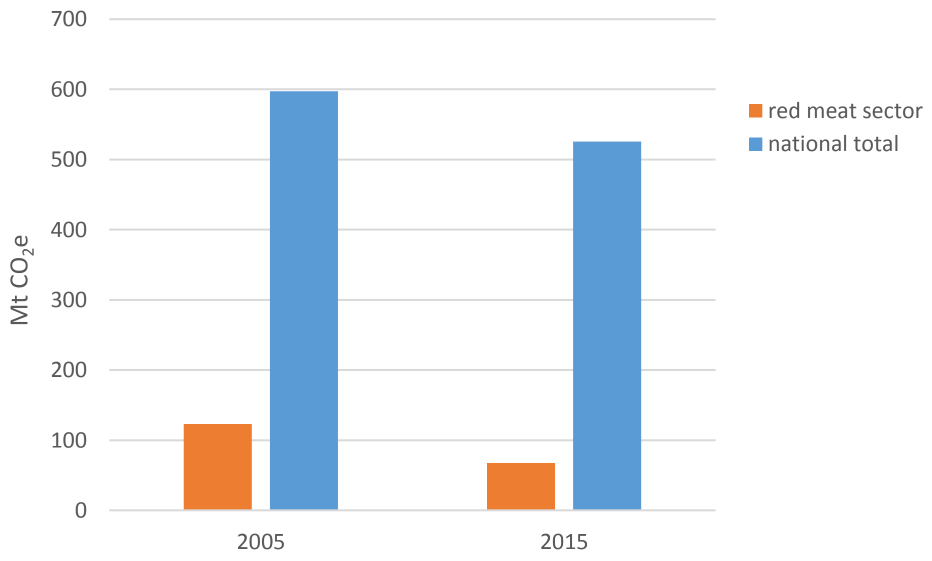

Figure 1. Greenhouse gas emissions from the red meat industry and total national emissions in 2005 and 2015.

In both 2005 and 2015 most emissions were associated with the pastoral component of the red meat sector (Figure 2). Feedlots, including emissions from livestock, manure, crop land and energy usage, accounted for 2.4% of emissions from red meat in 2005 and 4.8% in 2015. Emissions from the processing sector were 1.2% and 2.0% of the red meat sector in 2005 and 2015.

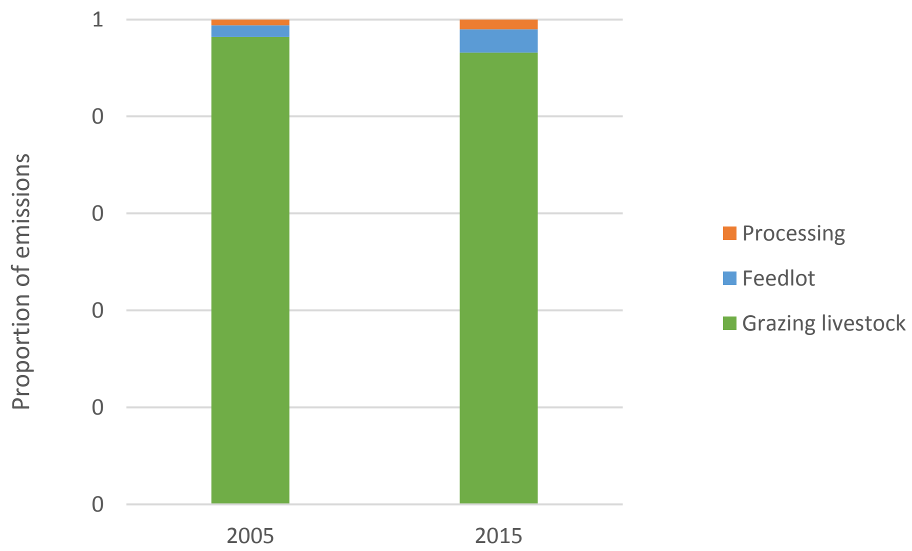

Figure 2. Proportion of GHG emissions from different parts of the red meat industry. Feedlot includes emissions from cropland used to supply grain to feedlots. Grazing livestock includes emissions from pastures and grasslands.

In 2005, half the emissions from the red meat industry were CO_2, mostly from deforestation (Figure 3). This decreased to 17% in 2015. Emissions from methane also decreased between 2005 and 2015, but the relative contribution increased from 41% to 67% of emissions from the red meat industry. Methane emissions were largely from enteric fermentation. Nitrous oxide emissions remained relatively stable, and were primarily associated with the decomposition of manure and urine.

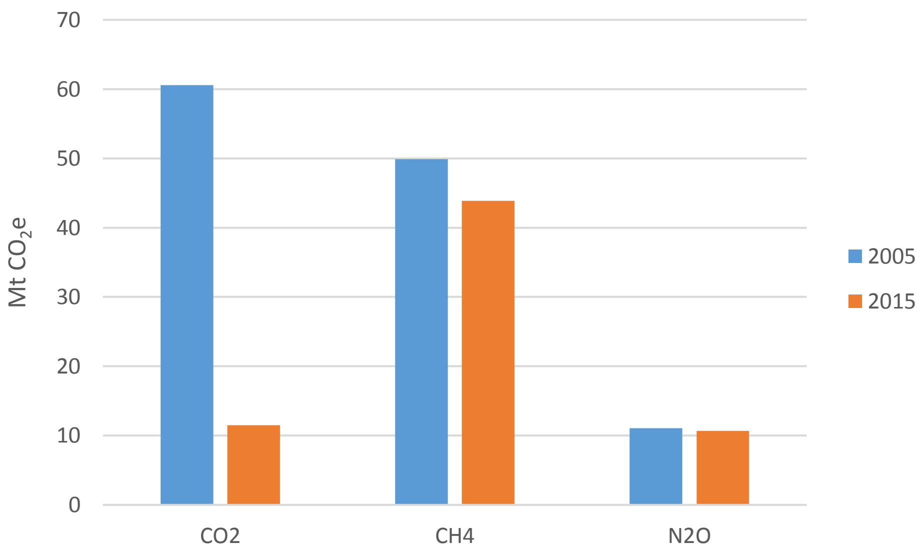

Figure 3. Greenhouse gas emissions from the red meat sector by source (excluding processing and energy use). CO_2 emissions are from land use and land use change, and application of urea and lime. CH_4 emissions are from enteric fermentation, land use and land use change and burning of agricultural residues. N_2O emissions are from agricultural soils, land use and land use change, manure management, and field burning of agricultural residues.

In both 2005 and 2015, the major sources of GHG emissions associated with the red meat sector were emissions from grasslands and enteric fermentation (Table 5). Agricultural soils and meat processing were also important contributors. Forest land (reforestation and afforestation) was the major sink for GHG emissions.

Most emissions from grassland were associated with conversion of forest land to grassland, with deforestation accounting for 87 and 92% of emissions from grassland in 2005 and 2015, respectively. Deforestation and re-clearing occurred primarily in Queensland, but New South Wales also had a significant contribution.

A total of 78% of emissions from enteric fermentation were from beef cattle on pasture. Approximately half these emissions were from cows greater than 2 years old. The location of beef cattle pasture emissions was reflected by cattle numbers; 44% of emissions from enteric fermentation were from Queensland and 22% from New South Wales. A total of 18% of emissions were from sheep meat production, with 3-4% from feedlot cattle and less than 1% from goats.

Over half of emissions from agricultural soils were associated with livestock, with emissions from application of manure, and urine and dung from grazing animals accounting for 57% of emissions from agricultural soils in 2005 and 51% in 2015. Urine and dung from grazing beef cattle were the major contributor.

The largest non-manure source of emissions from agricultural soils was emissions from decomposition of crop residues.

4.1.1 Mitigation options

Experts that participated in the Delphi survey tended to agree that land use management was the most promising option to reduce greenhouse gas emissions associated with the red meat industry (Figure 4). This included reforestation, savanna burning practices and reduced deforestation, and to a lesser extent, woody biomass growth. The use of methane inhibitors, animal genetics, reduced age at slaughter and days on feed, and vaccination against methanogens were also ranked as important practices. Improvements in soil carbon, feed digestibility, processing, and manure management were deemed to be less important, and were not explored in our pathways.

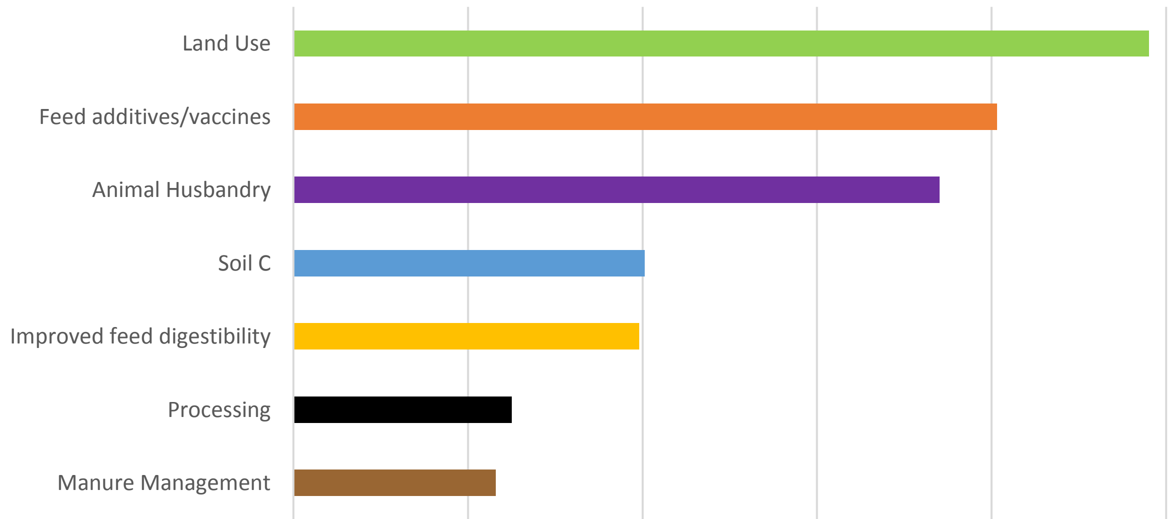

Figure 4. Relative importance of different mitigation options as determined by Delphi survey of industry experts. Larger bars indicate classes of mitigation options that were more highly ranked by survey participants. More detailed results are available in Appendix section 9.1

4.1.2 Pathways to CN30

4.1.2.1 *Business as usual*

If the number of beef cattle increases to 25 million, but the industry does not take any steps to reduce GHG emissions, total emissions from the red meat industry would increase from 68.5 Mt CO_2e in 2015 to 69.7 Mt CO_2e in 2030 (Figure 6). If Australia was able to meet the targets set under the Paris Agreement (either a 26% or 45% reduction in emissions from 2005 levels) by reducing emissions from other sectors, the proportion of emissions from the red meat sector would increase to between 16 and 21% (Figure 5).

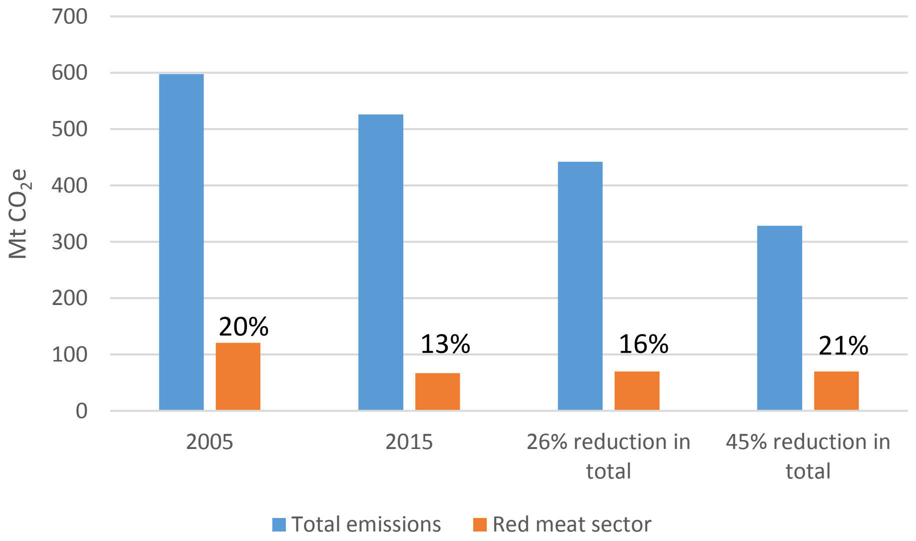

Figure 5. Emissions from red meat sector as a proportion of total Australian emissions in 2005, 2015, and for the business as usual pathway in 2030 if total national emissions were reduced by 26 and 45% as per the targets set by the LNP and ALP.

4.1.2.2 *Pathways that reduce GHG emissions*

Stopping deforestation and reducing methane emissions from enteric fermentation were key to reducing GHG emissions in the pathways evaluated in this study (Figure 6). Stopping deforestation avoided 30.1 Mt CO_2e, while methane emissions from enteric fermentation were reduced by between 4.5 and 29.7 Mt CO_2e compared to the *Business as usual* pathway (Table 6). Abatement of emissions from savanna burning management was also important, reducing 2015 emissions by 9.5 Mt CO_2e if practiced on 45 M ha.

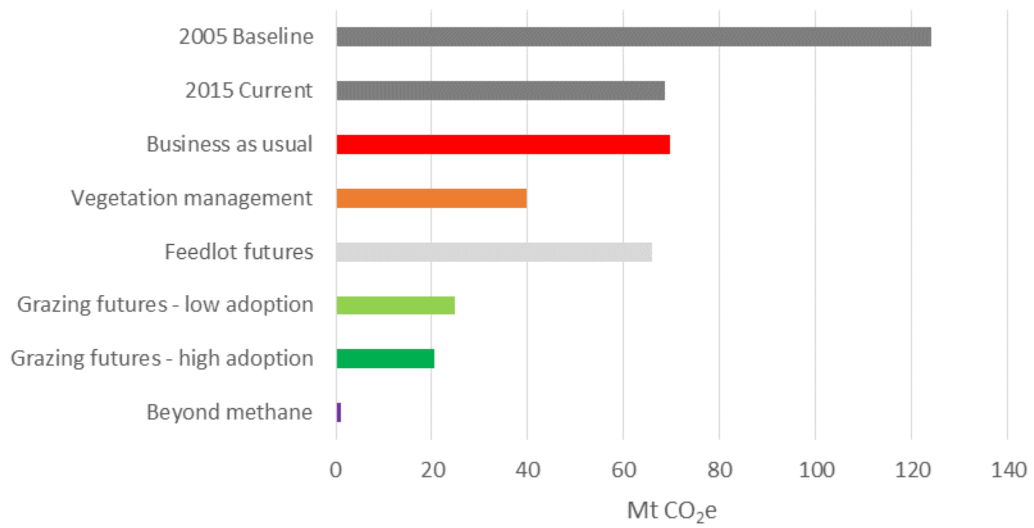

Figure 6. Greenhouse gas emissions from pathways to CN30 compared to 2005 baseline and 2015 (current) emissions. A summary of pathways is provided in Table 4.

The largest reductions in enteric methane emissions were achieved by substantially reducing emissions from grazing cattle (*Beyond methane*) (Table 6). Reducing emissions from 40% of the grazing herd (*Grazing futures – high adoption*) also resulted in large reductions. There was less benefit in reducing methane emissions from feedlot cattle (*Feedlot futures* pathway) or in small proportions of the grazing herd, though these pathways still contributed to an overall reduction in emissions.

Table 6. Reductions in enteric fermentation from beef cattle, sheep meat and goats in pathways to CN30

Pathway	**Enteric methane ($Mt\ CO_2e$)**	**Reduction in enteric methane compared to BAU ($Mt\ CO_2e$)**
Business as usual (BAU)	39.9	-
Vegetation management	39.9	-
Feedlot futures	35.4	4.5
Grazing futures – low adoption	34.0	5.9
Grazing futures – high adoption	29.8	10.1
Beyond methane	10.2	29.7

The *Beyond Methane* pathway provided the largest reductions in emissions (Figure 6), but relied on substantially reducing enteric methane fermentation from grazing animals, as well as zero deforestation and savanna burning management. Even with this disruptive pathway, carbon sequestration methods are required to achieve CN30.

4.1.2.3 *Offsetting remaining emissions*

Achieving a carbon neutral red meat industry by 2030 will require some degree of tree planting or revegetation (Figure 7). The area of trees required to offset remaining emissions from each pathway will vary depending on sequestration rates. For chenopod shrubs and fodder trees with relatively low sequestration rates (e.g. 0.7 t CO_2e/ha/year), more than 30 M ha (26% grazing land) is required to offset emissions. At higher sequestration rates of between 2 and 4 t CO_2e/ha/year, between 5 and 12 million ha of trees would be required to offset emissions from the grazing futures pathways. This is equivalent to between 5 and 11% of the current grassland area.

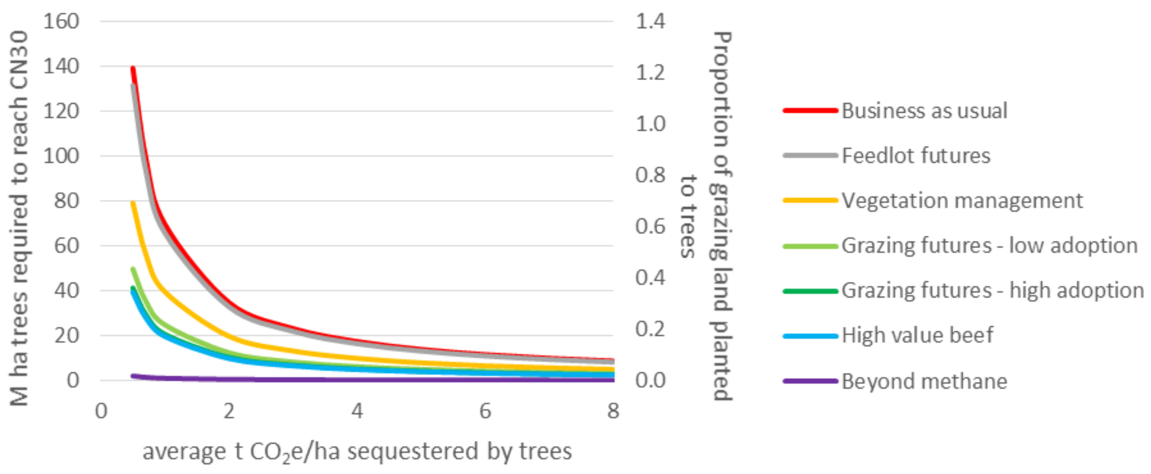

Figure 7. Area of trees required to offset emissions from pathways with variation in average C sequestration.

It was estimated that dung beetles could sequester between 4.6 and 5.1 Mt CO_2e, depending on the number of sheep and cattle in each pathway. Adoption of dung beetles could potentially reduce the area of tree planting required by 1-2 M ha.

4.1.2.4 *Economic feasibility*

The feasibility of each pathway is presented sequentially as marginal abatement cost curves (MACCs). These MACCs are initially presented in terms of their average costs for each of the practices followed by MACCs that consider producer heterogeneity and allocated reduction of emissions to those producers who can achieve abatement at the lowest cost. These costs also capture any productivity gains associated with the practices, as discussed in Section 3.2.3.3.

Costs for the *Feedlot futures* pathway are largely comprised of the cost of planting trees (Figure 9). This is due to the relatively minor reduction in emissions from the other practices in this pathway. The combined additional expected profit from the expansion of existing feedlots by building new pens and the creation of new feedlots to expand the number of feedlot cattle to 5.6 million by 2030, combined with the application of vaccinations and feed supplements has the potential, on average, to reduce emissions at no cost as the benefits of this strategy outweigh the costs. Genetic improvement and feedlot cattle vaccinations are also low-cost options but the quantity of emissions reduction from these practices are low relative to the quantity required to achieve carbon neutrality.

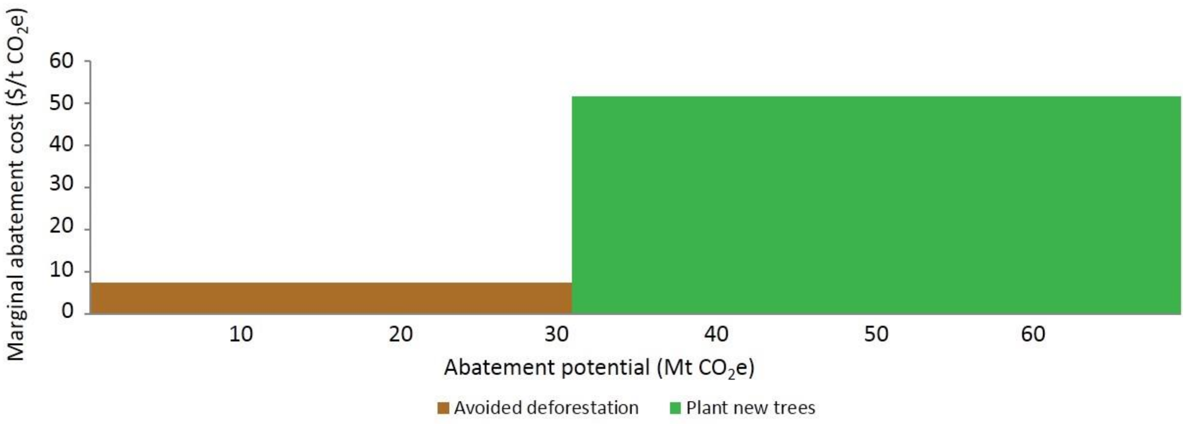

Figure 8. Marginal abatement cost curve for the Vegetation Management pathway. The practices shown in the legend are arranged in order of ascending costs.

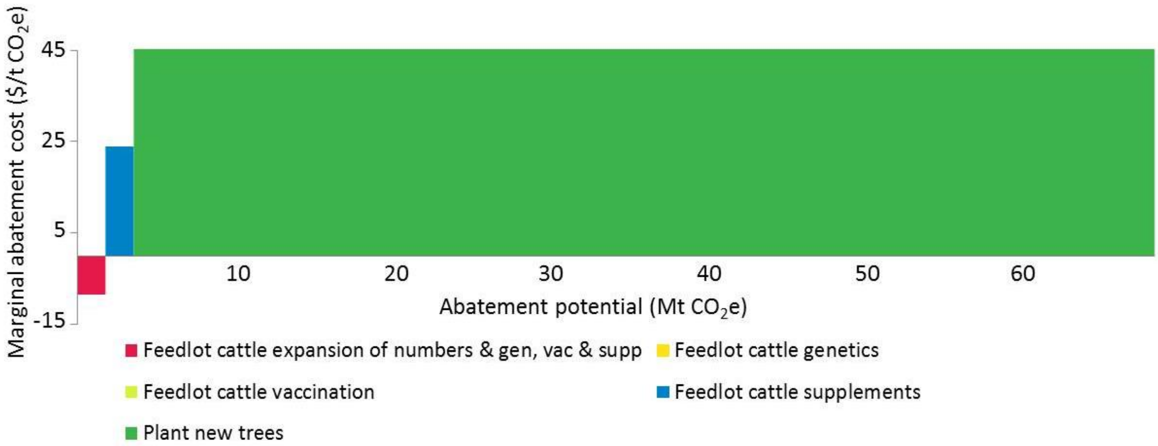

Figure 9. Marginal abatement cost curve for the Feedlot futures pathway. The practices shown in the legend are arranged in order of ascending costs. Some practices shown in the legend are not visible in the figure due to their relatively low quantity of carbon abatement

The *Grazing futures* pathways, both low and high adoption, include a more varied range of practices and average costs (Figure 10, Figure 11). Planting new legume species for sheep shows promise as an attractive emission-reduction option. On average, this practice is estimated to be profitable to producers, even in the absence of a carbon price. This does, however, assume that producers have access to the capital required to establish these pastures.

Emissions reduction from savanna burning management, when accounting for both emissions avoidance and the additional quantities of carbon sequestered in living woody biomass, has a relatively low average cost to the industry (< $5.00/t CO_2e) and results in a substantial reduction in emissions (almost 9.5 Mt CO_2e per year).

Avoided deforestation provides the single largest reduction in emissions and can also be achieved, on average, at a cost of less than a carbon market price of \$11.83/t CO_2e. This practice could reduce emissions by 30.1 Mt CO_2e.

Planting trees, fencing off marginal areas of farms in western Queensland, planting new legume species on suitable cattle producing farms and planting salt bush all have an average cost higher than the current market price of carbon. This suggests that additional incentives would be required for these practices to be adopted. The costs of these practices do, however, vary across regions and from farm to farm and the actual costs of these practices may be either lower or higher than the average values presented in specific situations. The average cost of planting trees also varies between the different pathways. This occurs due to the assumption that the lowest-cost areas will be planted to trees first. Subsequently, as the area of trees increase, the average price for this practice also increases.

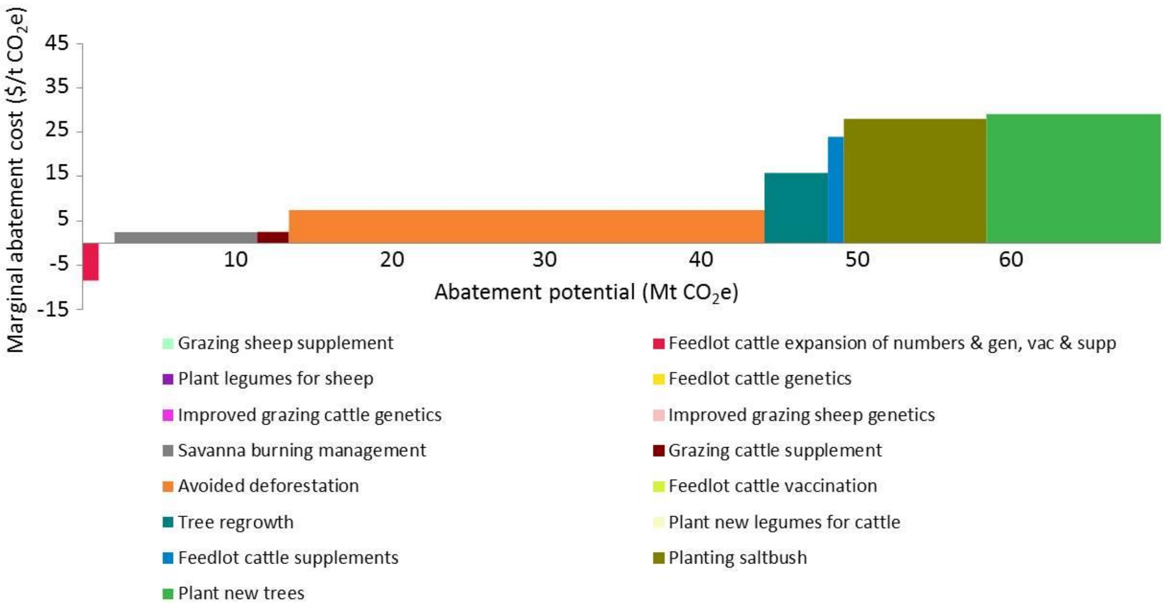

Figure 10. Marginal abatement cost curve for the Grazing futures – low adoption pathway. The practices shown in the legend are arranged in order of ascending costs. Some practices shown in the legend are not visible in the figure due to their relatively low quantity of carbon abatement

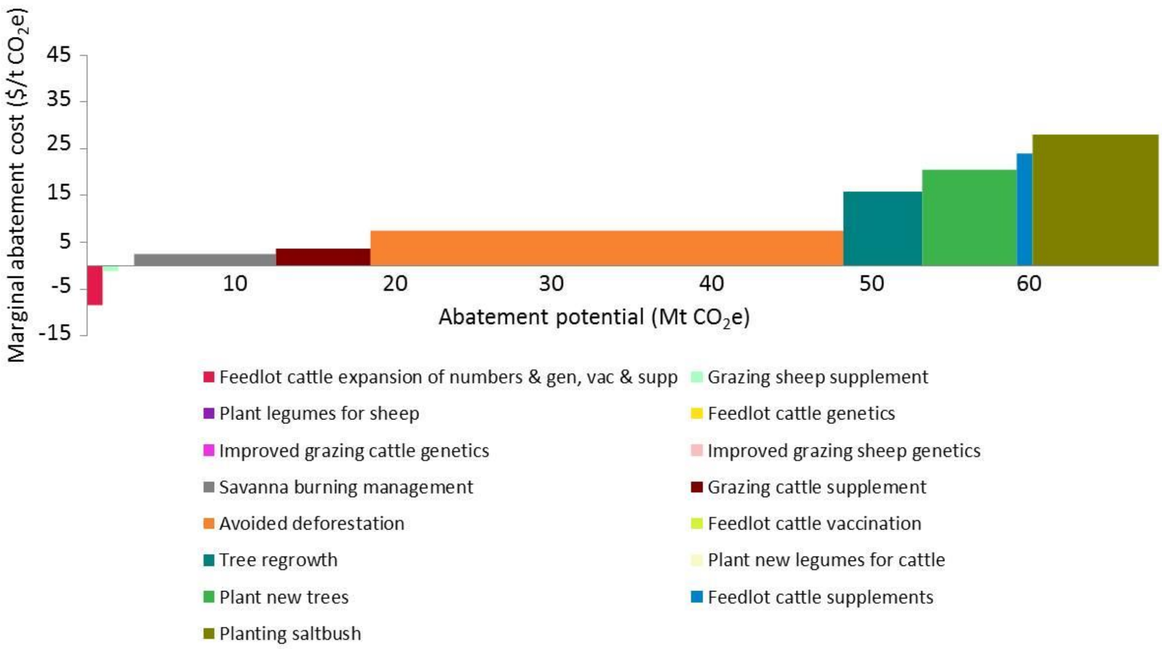

Figure 11. Marginal abatement cost curve for the Grazing futures – high adoption pathway. The practices shown in the legend are arranged in order of ascending costs. Some practices shown in the legend are not visible in the figure due to their relatively low quantity of carbon abatement.

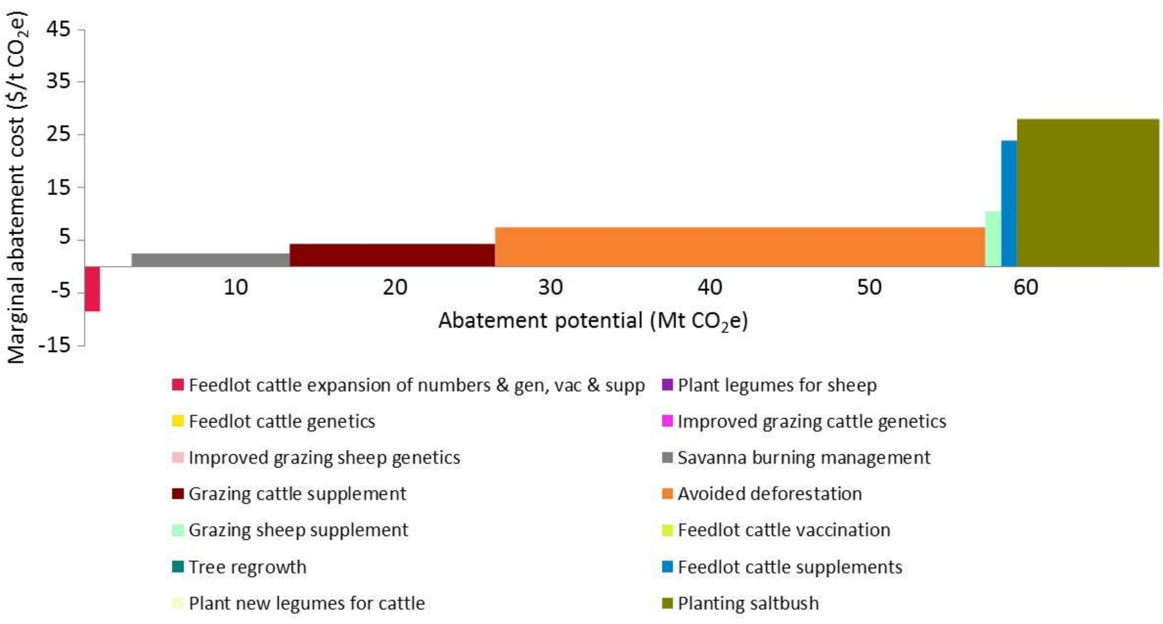

Figure 12. Marginal abatement cost curve for the beyond methane pathway. The practices shown in the legend are arranged in order of ascending costs. Some practices shown in the legend are not visible in the figure due to their relatively low quantity of carbon abatement.

For the *Beyond methane* pathway, a large proportion of emissions reduction can be achieved at a relatively low cost of < \$5/t CO_2e through the supply of a slow-release rumen bolus to cattle. This is based on the assumption that such a technology can be developed and released commercially before 2030 at a price of \$18 per head.

While not considered in our pathways, preliminary estimates on the establishment of dung beetle colonies in pastures production systems suggest that the benefits to production will outweigh the costs of purchasing and establishing the active colonies. Estimates suggest that on average landholders will receive a benefit of \$0.50/t CO_2e reduction in pasture cattle systems and \$0.04/t CO_2e reduction in sheep grazing systems. This suggests that if effective colonies can be established, producers should adopt this practice, even in the absence of a carbon price.

As already mentioned, while beneficial in terms of observing the average cost of the different practices in each pathway, the costs presented in Figure 9 to Figure 12 ignore the often quite large variance between different regions and the ability of different producers to undertake them. The marginal abatement cost curves which account for the variable costs and feasibility for different producers are presented in Figure 13. The dotted horizontal line represents the average price (\$11.83 per t CO_2e) from the first five auctions of the ERF. Emissions reductions that occur in regions of the curves under this line would be feasible at this carbon price.

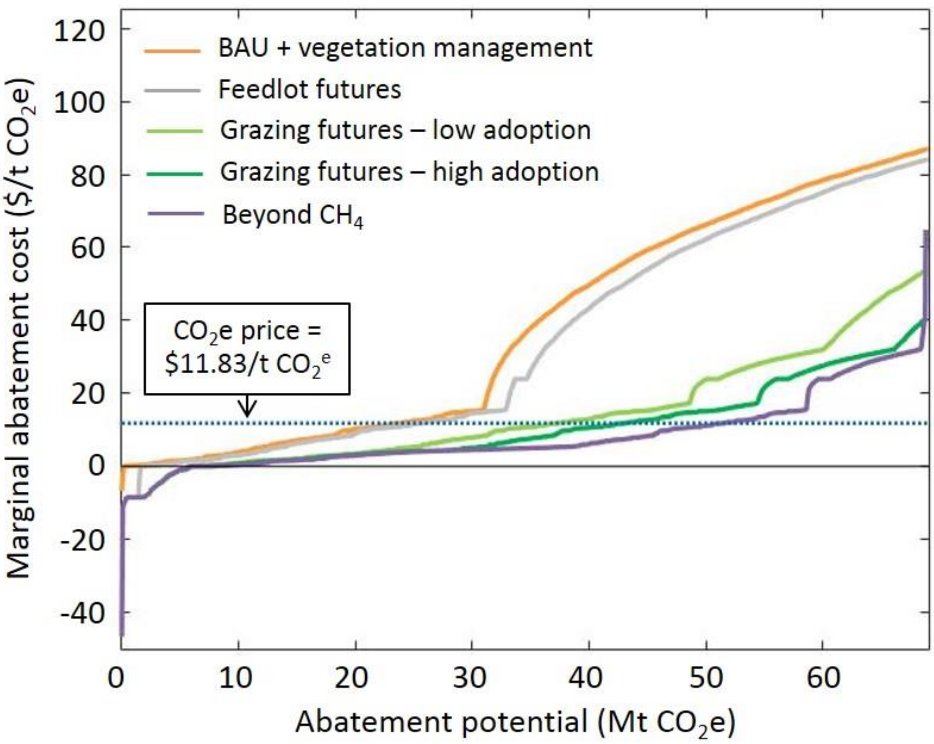

Figure 13. MACCs for the modelled pathways while accounting for the variable population of producers. The dotted horizontal line represents the average price (\$11.83 / t CO_2e) from the first five auctions of the ERF. Emission reduction that occur in regions of the curve under this line would be feasible at the carbon price.

4.1.2.5 *Total cost of achieving carbon neutrality*

The total cost of achieving carbon neutrality for the different pathways, in annualised present value terms, is presented in Table 7 .Total quantity of emissions for which it would be economically viable for producers to abate in 2030, at carbon market prices of $0, $11.83 and $50 per tonne of CO_2e are also presented in this table .These quantities of feasible emissions abatement include both the feasible abatement practices and the areas for which it is feasible to offset emissions through sequestration from tree plantings at each of the specified prices.

Table 7. Total annualised cost of achieving carbon neutrality in 2030 and the feasible quantities of abatement that could be achieved at different carbon prices

Pathway	**Total cost)$ millions(**	**Feasible emissions abatement)Mt CO_2e(**		
		$0	**$11.83**	**$50**
Vegetation management	2,229	1.46	23.95	40.15
Feedlot futures	1,974	1.60	25.85	43.07
Grazing futures -low adoption	911	5.79	37.47	67.03
Grazing futures -high adoption	709	6.01	43.19	68.79
Beyond methane	2,004	5.86	51.62	68.78

High adoption of the *Grazing futures* pathway provides the lowest-cost set of practices to achieve carbon neutrality by 2030. Under the assumptions listed in Section 3.2.3.3, it is estimated that the annualised present value of achieving carbon neutrality will be $709 million in 2030. This accounts around 3.5% of the current off-farm value of the Australian red meat industry.

While the high-adoption of *Grazing futures* provides the lowest total cost of achieving carbon neutrality, the *Beyond methane* pathway is projected to provide the highest quantity of abatement under the average ERF auction price assumption of $11.83 per tonne of CO_2e (Figure 13) .Under this pathway 75% of the emissions reductions required for the industry to become carbon neutral would be feasible to producers if their emissions reduction practices were covered by the ERF. This does, however, assume adequate investment into the research and development of the modelled practices to allow the implementation of these practices by 2030. This includes the assumption that an annual slow-release device to reduce enteric methane from livestock is available to producers for $18 per head for cattle, and that a low-cost feed supplement for feedlot livestock and new legume species become commercially available.

The economic analysis suggests that even in the absence of a carbon price, emissions will be reduced by approximately 8.5% of the amount required to achieve carbon neutrality in all pathways except the *Feedlot futures* pathway. This implies that these practices should be adopted by producers, even in the absence of any incentive payments, as they will result in an increased profitability through the predicted productivity gains.

The projected productivity gains for several of the modelled practices were a significant driver of their feasibility .To test the impact of these assumptions, in Table 8 we present the total annualised cost of achieving carbon neutrality in 2030 via the different pathways under the assumption that only half of the productivity gains projected are realised .

Table 8. Total annualised cost of achieving carbon neutrality in 2030 when the productivity gain assumptions are reduced

Pathway	**Total cost)$ millions(**	**Feasible emissions abatement)Mt CO_2e(**		
		$0	**$11.83**	**$50**
Vegetation management	2,495	0.03	23.54	37.20
Feedlot futures	2,215	1.48	25.44	40.11
Grazing futures -low adoption	2,011	1.94	36.92	63.94
Grazing futures -high adoption	2,746	2.07	39.21	68.23
Beyond methane	4,520	2.04	40.20	67.51

Lower productivity gains than projected has a large impact on the total annualised cost of achieving carbon neutrality. A 50% reduction in this assumption leads to an increase in the cost of achieving carbon neutrality by up to 290%. It also reduces the quantity of emissions abatement that could be achieved in the absence of a carbon market (third column in Table 8). Only 3% of the required emissions reduction to achieve carbon neutrality would occur if this were the case. This highlights the importance of further research into the robust quantification of productivity gains associated with reduced methane emissions.

5 Discussion

5.1 GHG emissions from the red meat sector

This report provides the most complete overview of emissions from the Australian red meat industry to date. Total emissions from red meat (124.1 Mt CO_2e in 2005) are higher than values previously reported for livestock or agriculture because they include GHG emissions from land clearing, which is reported under land use change in the inventory.

The advantage of using the National GHG Inventory as the basis for calculations is that this method can be applied to future inventories to track emissions from the red meat industry over time. Retrospective changes to 2005 baseline emissions can also be accounted for as methods used in the inventory are reviewed and refined.

Some methods and emissions factors used in the inventory may currently under- or overestimate emissions from some sources. For example, Wiedemann *et al.* (2017) report that the inventory likely overestimates emissions from beef cattle feedlot manure. This could be by as much as 50%. Similarly, assumptions used by the inventory regarding size of cattle and length of time on feed in feedlots have not been updated since 2010 and likely lead to underestimates of enteric methane fermentation from feedlots in 2015.

In addition, the baseline used in this study may overestimate emissions from the red meat sector due to limitations of the data used to allocated emissions to red meat. However, areas where the authors were unable to accurately allocate emissions between red meat production and other industries (e.g. dairy, wool) provided relatively minor contributions to baseline total, so the change to baseline emissions would be minor.

This study also highlights the large reduction in GHG emissions from the red meat industry between 2005 and 2015. This reduction (55.5 Mt CO_2e) represents 77% of the reduction in total national emissions during this period. Almost all of the reduction in emissions during this period were from a reduction in deforestation. However, even if the industry achieves zero deforestation by 2030, additional interventions will still be required to become carbon neutral.

5.2 Pathways to CN30

The pathways presented in this study provide an indication of how the Australian red meat industry can reduce GHG emissions, and the type and scale of interventions required to achieve CN30. While these pathways focused on the most promising methods to reduce GHG emissions and sequester carbon, other methods not considered in our pathways may still play an important role in reducing and offsetting GHG emissions.

5.2.1 Reducing GHG emissions

A reduction in deforestation is essential to achieve CN30. The reduction in emissions from permanent conversion of forest land to grassland between 2005 and 2015 was driven primarily by policies that restrict land clearing. However, this decrease has been reduced by recent changes in policy in Queensland that have reduced these restrictions (Vegetation Management Framework

Amendment Act 2013). In addition to being a major source of GHG emissions, land clearing contributes to a loss of habitat for native species, and runoff of sediment in reef catchments (Reside *et al.* 2017).

It is important to highlight here that avoidance of deforestation in the pathways did not include changes to temporary clearing and re-clearing of woody vegetation and forest land as happens in areas of western Queensland. While re-clearing produces GHG emissions, the area of clearing is balanced by the area of re-growth (Commonwealth of Australia 2017e, figures 6.4 and 6.5b).

Reducing methane emissions from ruminant livestock is also key to reducing emissions from the red meat industry and achieving CN30. Preventing methane emissions from ruminants through feed additives has long been a goal of the livestock industry, but compounds used in these methods need to be safe for the animal, consumers of livestock products, and the environment (Henderson *et al.* 2016). The pathways evaluated in this study show that reductions in enteric methane need to be large, and applied to a high proportion of ruminant livestock to have a significant impact. Many feed additives and supplements that reduce enteric methane emissions need to be delivered frequently (daily) and consistently to produce a sustained reductions in emissions. The challenge here is that the bulk of the Australian enteric methane emissions come from cattle and sheep grazing pastures. It is difficult to provide supplements to extensively managed livestock, particularly in northern Australia where graziers may only handle their cattle once or twice a year. Thus, in addition to continued development and commercialisation of feed additives to reduce enteric methane, new technologies and delivery methods are required to provide them to grazing animals for this to be a viable option by 2030.

More practical options for grazing cattle and sheep include vaccines and breeding of low-methane emitting animals. Scientists are still working to create a successful anti-methane vaccine, but the potential application to grazing industries make this an important part of CN30 pathways (Wedlock *et al.* 2013). While potential reductions in methane from vaccines are only 5-20%, their wide applicability to grazing ruminants means that they will potentially have a greater impact on national enteric methane emissions compared to feed additives that almost eliminate methane emissions, but can only practically be fed to a small portion of animals. Similarly, it is estimated that selective breeding could reduce methane emissions by around 15% (Buddle *et al.* 2011; Eckard *et al.* 2010; Hristov *et al.* 2013), but this method requires little or no changes to animal management and production systems.

Faster growth rates and earlier age of slaughter of beef cattle as per the *Feedlot Futures* pathway can also reduce GHG emissions. This is achieved by reducing the length of time cattle spend grazing pasture, and provision of higher quality grain-based diets for several months prior to slaughter. While the total number of cattle was reduced in the *Feedlot Futures* pathway, producers may actually maintain stocking rates and on-farm numbers, thus the reduction in emissions may be smaller than that estimated here. In addition, increasing the number of feedlot cattle increases the requirement of grain for livestock feed. Other animal husbandry and management options to decrease enteric methane emissions from the whole cattle herd would include increasing the quality of feed available to grazing cattle (improved pastures, legumes, supplements), improved breed management to increase weaning rates and culling of unproductive animals.

Savanna burning management was also shown to be an important part of pathways to CN30. The uptake of savanna burning projects under the ERF has been impressive. As of July 2017, there were 74 registered projects on 31 M ha, with almost 400 million ACCUs issued (Andrew Edwards *pers comm*). 41 of these projects were on pastoral properties. The ability to earn ACCUs has been an incentive for pastoral properties to adopt savanna burning management, with projects providing additional benefits such as improved biodiversity (Russell-Smith and Whitehead 2015). Carbon prices will likely remain a key driver of uptake of savanna burning management projects. Heckbert *et al.* (2012) estimate that at \$23/t CO_2e, fire management would be viable across 51 M ha of northern Australia. This would increase to nearly 83 M ha if the carbon price increased to \$40/t CO_2e.

5.2.2 Sequestering carbon

The red meat industry will need to invest in new methods to sequester carbon; none of the pathways in this study achieved carbon neutrality. Afforestation and revegetation of grazing land will likely be the main method for sequestering carbon in the short to medium term. This study provides an indication of the scale of tree planting required to offset remaining emissions from the various pathways investigated (Figure 7). An estimated 5 to 12 M ha of afforestation would be required, depending on the types and location of trees, and the extent of GHG mitigation from other practices. This area of trees does not necessarily need to be large blocks of environmental plantings on good quality agricultural land. Paul *et al.* (2016) reported that narrow belts of mallee plantings on 5% of marginal land (<\$2000/ha, approx. 18 M ha) could sequester between 17 and 26 Mt CO_2e/year. Integration of forests into farms can have additional environmental benefits including reduced erosion, reduced risk of waterlogging and flooding, mitigation of dryland salinity, and improved water quality (Paul *et al.* 2013). They may also provide valuable shade and shelter for grazing livestock. However, it is important to note that even small areas of environmental plantings reduce area available for pastures or cropping. Forests also need to be managed to avoid increased fire risk.

The low carbon sequestration rate of fodder trees such as Leucaena mean that offsetting emissions from the red meat industry through this option alone is not feasible. However, increasing the area of trees available for grazing would reduce the area of land planted to trees as environmental plantings. Walden *et al.* (2017) reported that 5.7 M ha of saline or marginal land could be revegetated with *Atriplex* (saltbush) species, with an annual sequestration rate of between 4 and 12.5 Mt CO_2e/year. This would reduce the area of land planted to ungrazed trees by several million ha, so may still be a valuable part of reaching CN30. In addition, grazing of fodder trees such as leucaena may decrease methane emissions from ruminant livestock (Harrison *et al.* 2015).

Similarly, there may be opportunities to sequester small amounts of carbon in soil through improved pasture growth and grazing management practices. There is conflicting evidence in the literature about the scale of carbon sequestration possible in Australian grazing systems, and the amounts of carbon sequestered are likely to be small compared to trees and other woody vegetation. For example, Sanderman *et al.* (2010) report potential gains of 0.1-0.3 t C/ha/year (equivalent to 0.4-1.1 t CO_2e/ha/year) through pasture improvements such as fertilisation, irrigation and sowing of more productive varieties. However, this would not be achieved in all grazing systems. An increase in soil organic carbon is unlikely in systems with poor soils (low clay content, low soil fertility, low porosity), low average rainfall (<600 mm) and/or susceptible to drought, flood, frost, extreme heat or cold (Commonwealth of Australia 2018). In addition, methods to increase pasture growth such as fertilisation and irrigation need to be carefully managed because they can also increase N_2O emissions through increased N leaching and runoff.

While sequestration of carbon by dung beetles provides an additional option to sequester carbon in agricultural landscapes, more research is required to better understand the sequestration potential of different species currently available in Australia.

The study revealed that the cost of planting trees and fencing off marginal areas of land for regeneration of woody vegetation was higher than the current market price for carbon. Despite this, there has been high registration rates for ERF projects concerned with reforestation, afforestation, and regeneration of native forest. Analysis indicated that the cost of tree planting varies between locations. Assuming the lowest-cost areas are planted to trees first, this means that the rate of tree planting and uptake of ERF projects may start to decline, and that higher economic incentives are required to maintain this practice. Alternatively, the opportunity to earn income through the ERF may only be a small part of the motivation for land owners to plant trees given the environmental and potential productivity benefits mentioned above.

5.2.3 Feedlots and meat processing

While emissions from feedlots and processing provided relatively small contributions to baseline emissions, reducing emissions from these sectors is still important.

Methods to reduce GHG emissions from feedlots are already available, and more easily adopted compared to methods that would be used by the grazing industry. For example, it is very easy to manipulate the diet of lot-fed animals, and it is not unlikely that enteric methane fermentation could be eliminated from this sector, with the potential added benefit of improved feed efficiency and growth rates. Reduced days on feed via increased average daily gain could also reduce emissions per head or kg beef (Hristov *et al.* 2013). The number of feedlot cattle increased by 14% between 2005 and 2015, and may continue to rise, thus increasing the importance of reducing emissions from this sector. In addition, individual feedlots may see benefits in achieving carbon neutrality.

Similarly, the processing sector may wish to become carbon neutral independent of other parts of the red meat industry. The Australian Meat Processing Corporation has previously set goals to reduce GHG emissions by 20% between 2008/09 and 2015 under the Red Meat Processing Industry Climate Change Strategy (AMPC 2012), with some individual processors also setting formal GHG emissions reduction targets (Ridoutt et al 2015). Between 2008/09 and 2013, emissions from processing were reduced by more than 20% per t HSCW, primarily through improved energy use efficiency (Ridoutt *et al.* 2015). Reductions in emissions were also achieved through installation of covers to anaerobic lagoons, biogas capture from wastewater treatment, and upgrades to wastewater treatment plants. These methods also had other benefits such as reducing odour complaints and energy use.

5.3 Incentives for change

Given the cost of reducing emissions to achieve CN30, policy support and incentives for those involved in the red meat sector will be required to enable widespread adoption.

Policies to reduce deforestation

Rates of primary deforestation in Australia are closely linked to government policy. The large reductions in emissions from deforestation between 2005 and 2015 were the result of policies that restricted the clearing of native vegetation. In Queensland, where most land clearing in Australia occurs, the *Vegetation Management Act* banned broad scale clearing of remnant vegetation, and was later strengthened to include high value regrowth forests (Reside *et al.* 2017). In 2013, the *Vegetation Management Framework Amendment Act* relaxed restrictions on land clearing, and emissions from deforestation in Queensland subsequently increased.

Re-establishing controls to restrict the clearing of primary forests would be one way to achieve reduced or zero deforestation. This could occur via a total ban on deforestation, or a cap on land clearing, alongside regional retention rates for specific vegetation types (Reside *et al.* 2017).

Alternatively, incentives such as payment under the ERF or an alternative carbon market could be used to reward land holders for avoided deforestation.

The Emissions Reduction Fund

The ERF has been a key part of government policy to reduce GHG emissions. Current ERF methods relevant to the red meat sector include:

- Vegetation projects
  - Avoided clearing of native regrowth
  - Avoided deforestation
  - Reforestation and afforestation
- Savanna fire management
- Agriculture projects
  - Beef cattle herd management (for cattle fed principally from grazing or forage) – improved feeding and breeding practices to increase productivity and decrease emissions intensity.
  - Reducing GHG emissions in beef cattle through feeding nitrate containing supplements (replacing urea lick blocks with nitrate lick blocks)
  - Sequestering carbon in soils in grazing systems

Details of projects can be downloaded from the Clean Energy Regulator website: http://www.cleanenergyregulator.gov.au/ERF/project-and-contracts-registers/project-register. Most projects and ACCUs issued as part of the ERF have been for vegetation projects (Table 9). There has also been good uptake of savanna burning projects. Thus, despite the perceived conflicts between revegetation, avoided land clearing and fire management with fodder production for grazing livestock, the ERF or similar programs may provide enough incentive for land managers to change land management practices to reduce GHG emissions and sequester carbon. Our economic analyses indicate that both savanna burning management and avoided deforestation can be implemented at a lower cost than the current ERF carbon price, and this may be a factor in the widespread uptake of these projects.

Table 9. Summary of emissions abatement from the ERF as of April 2017. Data from the Clean Energy Regulator.

Method	Number projects	ACCUs issued
Vegetation	371	23,011,925
Landfill and waste	136	15,562,225
Savanna burning	74	4,069,843
Agriculture	46	343,122
Energy efficiency	51	141,410
Industrial fugitives	14	0
Transport	7	0
Total	699	42,363,030

Of the 46 registered agriculture projects, only 3 are for beef cattle herd management, and no ACCUs have been issued. There are no registered projects for feeding nitrate containing supplements. Most agriculture projects (32) are for sequestration of carbon in grazing systems, and all the ACCUs issued have been for destruction of methane in piggeries. Such low uptake of ERF projects for beef herd management and feeding of supplements indicates that this program does not provide sufficient incentive for producers to change grazing herd management practices. This is despite these practices potentially leading to increased productivity. The low level of uptake could be because the methods are not attractive to producers, the process of registering for ERF projects is too onerous, or the income from earning ACCUs does not justify the compliance costs and changes in farm management. A better understanding of factors influencing uptake of ERF projects would be useful. However, it appears that the ERF may not the best way to incentivise producers to reduce methane emissions from ruminant livestock with the current price settings.

The government initially allocated $2.55 billion to the ERF, but with $2.23 billion already spent on ERF auctions, there is only $320 million remaining (Clean Energy Regulator 2017). Continuation of ERF projects to reduce national GHG emissions from agriculture and other sectors will require continued investment and support from the government or private investors. Analysis shows that large reductions in GHG emissions from the red meat industry are feasible at the current carbon price of $11.83/t CO_2e, but only a small portion of methods are profitable without a carbon price.

It is also important to highlight here that not all reductions in GHG emissions and increases in carbon sequestration achieved through the ERF are accounted for in the inventory. This is discussed in more detail in the following section (5.4), and is an important area for future research.

Evidence of production benefits to producers

Producers are more likely to engage in methods to reduce GHG emissions if they are shown increase production, production efficiency and/or income, or decrease economic risk. As described above, the ERF and potential future carbon trading markets provide producers with an opportunity to diversity business income by generating income from the sale of ACCUs. Several methods in the above pathways are likely to result in production or economic benefits to producers, but in many cases the benefits have not been well described or quantified, for example:

- Potential increases in growth rates and feed conversion efficiency from ruminants with decreased methane production (feed additives, supplements, vaccines)
- Economic benefits from improved herd management (increased weaning rates, culling of unproductive cows)
- Production benefits from shade provided by trees. The impact of heat stress in feedlot cattle is well studied, but benefits from provision of natural shade for grazing animals requires research.

Increased red meat prices

A price premium for 'carbon neutral beef' could be another method to encourage industry to adopt practices that reduce GHG emissions. This premium could be attached in the same way that the poultry industry market 'free-range' eggs or the horticultural industry market 'organic' produce for a price premium.

5.4 Demonstrating reduction in GHG emissions from the red meat industry

Changes in emissions and sequestration must be measured in a way that is consistent with the Intergovernmental Panel on Climate Change (IPCC) guidelines (IPCC 2006) and included in the National GHG inventory. ERF methods may provide a basis for inclusion of some of these mitigation options in the inventory, but there is currently no link between ERF methods and the inventory. In addition, producers may actively reduce GHG emissions from their enterprise without engaging in an ERF project - possibly due to onerous registration, monitoring and reporting requirements. This would result in emission reduction or offset being unaccounted for.

For some activities, changes in emissions are already accounted for in the inventory. For example, the inventory currently measures land use, types of vegetation and biomass burning, so afforestation of grassland and savanna burning will be included in the inventory, and can be attributed to the red meat industry using the methodology from this study. Updates to methods used in the inventory to measure land use change will increase the accuracy of these estimates – both the calculation of emissions/sequestration from revegetation, afforestation and burning, and the allocation of emissions to the red meat industry. A key component of this will be improvements in the resolution of satellite imagery that will allow the inventory to measure areas of forest land and fire less than 25 m^2. This is important because afforestation of agricultural land may occur at a fine scale (e.g. trees along fence lines or in alleys as suggested by Paul *et al.* (2016)). In addition, more work needs to be done to characterise woody thickening (increase in height, basal cover and canopy cover of existing trees) to account for carbon sequestered in shrubs and other sparse woody vegetation.

For other methods to reduce GHG emissions, there is either no ERF method, or the reduction in emissions achieved through the ERF are not fully accounted for in the inventory. For example, the ERF herd management method attributes reductions in GHG emissions to changes in herd structure and productivity. Animal census data underpinning the inventory would reflect changes in herd size and structure, but would not account for changes in animal weight or growth rate. Similarly, while there is an ERF method for feeding nitrate-containing supplements to grazing animals, any reductions in enteric methane fermentation are not currently accounted for in the inventory. Similar

ERF methods could be developed to account for provision of feed additives or vaccines to reduce methane fermentation. Reductions in GHG emissions resulting from these methods is potentially very large, so it is imperative that changes in emissions are accounted for in the inventory.

5.5 Achievement of project objectives

Objective	Details	Achievement against objective
1	Establish an emissions baseline for the Australian red meat industry that is consistent with the national inventory. The project boundaries are the farm and meat processing sectors of the beef and sheep industries of Australia.	Baseline emissions were reported for the red meat industry in 2005, including emissions from livestock, agricultural soils, processing, transport, land use and land use change. Emissions for 2015 were also reported.
2	Identify and quantify the most promising GHG emissions mitigation and offset practices that are either available or likely to be available during the analytical time horizon.	Opportunities to reduce GHG emissions from the red meat industry were identified through review of literature, expert interviews and a Delphi survey.
3	Identify and quantify the impacts of the above practices that are likely to succeed based on applicability (i.e. how widely within the Australian red meat industry they can be applied), feasibility (i.e. how easily from a management perspective the practices can be applied) and cost effectiveness.	The impacts of promising mitigation options were quantified and applied in the pathways in objective 4.
4	Identify a series of pathways or scenarios that would allow the industry to become carbon neutrality by 2030, exploring the policy options needed to incentivise practice uptake.	Pathways to CN30 were explored during this project.

6 Conclusions/recommendations

Opportunities exist for the Australian red meat industry to substantially reduce emissions, and even become carbon neutral. A carbon neutral red meat industry will be reliant on a reduction in emissions from livestock and improved land management practices to reduce emissions and sequester carbon. These pathways will require appropriate policy support mechanisms, such as the Emissions Reduction Fund, and would be helped by consumers being prepared to pay a sufficient premium for carbon neutral red meat to enable the Australian red meat industry to invest in carbon mitigation and sequestration initiatives.

While this study reports on potential pathways to CN30, further research and development will be required. Specifically:

1. Methods to quickly, accurately and regularly measure and monitor reductions in GHG emissions from the red meat industry.
2. Research to update the National GHG inventory so that it more accurately reflects emissions from the Australian red meat industry.
3. Research to reduce methane emissions from livestock. Current research methods into methane inhibitors needs to be accompanied by methods to deliver feed additives and supplements to grazing livestock.
4. Research to quantify and improve productivity gains in sheep flocks and establish ERF methods to support mitigation.
5. Direct engagement with the Australian government to ensure that appropriate offset methods are prioritised, developed, and accounted for in the national inventory.
6. Further research to quantify the potential for mixed grazing and carbon sequestration options that maintain grazing performance while sequestering significant amounts of carbon. This could include sequestration by dung beetles (e.g. which species, how to maintain active populations, and how to measure sequestration).
7. Research into new legume and shrub species that can reduce methane emissions as well as increasing the quality of livestock feed in extensive grazing systems, and potentially sequester carbon.
8. Research to quantify and demonstrate production benefits from activities that reduce GHG emissions (e.g. feed additives, shade from tree planting).
9. Research into savanna burning management. Russell-Smith *et al.* (2015a) provide an overview of significant issues relating to the ongoing development and application of savanna burning projects in northern Australia. Key researchable issues include mapping of fire and fuel, and further development of methods for emissions abatement and C sequestration (e.g. assessing and modelling woody fuel dynamics, remote sensing for measuring changes in biomass). They also highlight challenges with implementation of savanna burning projects, and national and international policies.

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8 Glossary

Afforestation. Establishment of forest in an area where there was no previous tree cover. Forests may be established through planting events or natural regeneration.

Anaerobic decomposition. Decomposition in the absence of oxygen.

Annualised present value. A technique that converts revenue and costs streams which occur over several years into their annualised equivalent, expressed in present day values. This allows the comparison of activities with multi-year time frames, such as the planting of legumes, with other activities which can be completed within a single year.

Anthropogenic emissions. Emissions resulting from human activities.

Atmospheric deposition. The process by which gases and particles are removed from the atmosphere and deposited on the Earth's surfaces.

Baseline emissions. Emissions from the red meat industry in 2005.

Carbon neutral. Net zero carbon emissions. Any greenhouse gas emissions are offset by carbon sequestration.

Carbon sequestration. Removal of carbon from the atmosphere and storage in vegetation, soils or elsewhere.

Chenopod. Shrubs from the family Chenopodiaceae. E.g. Saltbush (*Atriplex* species).

CO_2e. Carbon dioxide equivalent. A common unit for comparing different greenhouse gases.

1 CO_2 = 1 CO_2e

1 CH_4 = 25 CO_2e

1 N_2O = 298 CO_2e

Deforestation. Permanent conversion of forest land to non-forest (grassland, crop land, settlements).

Delphi survey. A survey to gain consensus among experts. The survey is conducted in two or more rounds, where the results of the previous round are provided as feedback. Delphi surveys are commonly used in fore sighting and to prioritise goals.

Direct emissions. Greenhouse gas emissions released directly from an activity. E.g. methane from enteric fermentation, methane and nitrous oxide from decomposition of manure.

Discount rate. The value of money received by a landholder at some point in the future will be worth less than the same amount of money received today. A discount rate is a parameter value used to convert money expected at some point in the future to the equivalent in today's terms.

Enteric methane. Fermentation of methane during the digestion of feed by ruminant animals.

ERF. Emissions Reduction Fund. A voluntary scheme run by the Australian Government to provide monetary incentives for organisations and individuals to adopt practices that reduce greenhouse gas emissions or sequester carbon. Eligible activities earn carbon credits, which can be sold to generate income.

Fodder trees. Trees such as Leucaena that are grown to provide feed for livestock.

Forest land. A vegetation type dominated by trees. An area of at least 0.2 ha with a tree height of at least 2 metres and crown canopy cover of > 20%. It also includes lands with a woody biomass vegetation structure that currently fall below but which, *in situ*, could potentially reach the threshold values of the definition of forest land (e.g. young natural stands and plantations, cleared land that is expected to revert to forest). Does not include orchards and other woody horticulture – these are classified as crop land.

Grasslands. Rangelands and permanent pastures. Includes areas of sparse woody vegetation that do not meet the definition of forest.

Greenhouse gas. Gases that contribute to global warming. The main gases associated with the red meat industry are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Heterogeneity. The recognition that farms are not all similar in nature but rather vary according to a range of factors including farm size, labour and capital availability, efficiency of practices, enterprises undertaken and natural resource endowments.

Histosol. Soil consisting primarily of organic materials. E.g. peat. Cultivation of histosol soils releases nitrous oxide.

HSCW. Hot standard carcass weight.

Indirect emissions. Greenhouse gas emissions that occur indirectly as a consequence of an activity. E.g. nitrous oxide emissions from leaching of N from manure or fertiliser.

Land use change. Permanent change in land use, e.g. from forest land to grassland or crop land.

Leaching. Process by which soluble substances (e.g. nitrogen) are washed from soil or waste.

Livestock. For the purpose of this report, 'livestock' refers to beef cattle, sheep and goats.

Marginal abatement costs. The costs, through either abatement or mitigation practices, of reducing one additional tonne of CO_2e emissions.

Mt. Mega tonne. Equivalent to 1 million tonnes.

Net present value. A measurement technique which takes into account the revenues and costs of activities that will occur over time while also accounting for the time value of money and converting all values in terms of the current time's value.

Paris Agreement. A global agreement to combat climate change. Countries participating in the agreement develop national plans to reduce greenhouse gas emissions. Australia has committed to reducing national greenhouse gas emissions by 26-28% of 2005 levels by 2030.

Plantation. Intensively managed stand of trees of either native or exotic species.

Primary forest. Mature forest that has not previously been cleared or harvested.

Reforestation. Establishment of forest on land that historically contained forest but was converted to another land use.

Ruminant. A mammal that can obtain energy from plants by microbial fermentation in a specialised stomach. Cattle, sheep and goats are ruminants.

Savanna burning management. Controlled fire management in the northern Savannas to reduce the area of land burnt each year and the timing of burning. Controlled fires in the early dry season tend to be less intense and emit less greenhouse gases compared to wildfires in the late dry season due to lower fuel loads.

Sink. Any process, mechanism or activity that removes greenhouse gas, an aerosol or precursor of a greenhouse gas from the atmosphere.

Stochastic. The application of random values to defined probability distributions allowing the variability in the farm population to be modelled and analysed statistically.

UNFCCC. United Nations Framework Convention on Climate Change. An international environmental treaty which entered into force in 1994. Parties to the convention have agreed to work towards achieving the ultimate aim of stabilising 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.

Woody vegetation. Shrubs and trees.

9 Appendix

9.1 Detailed results from Delphi survey

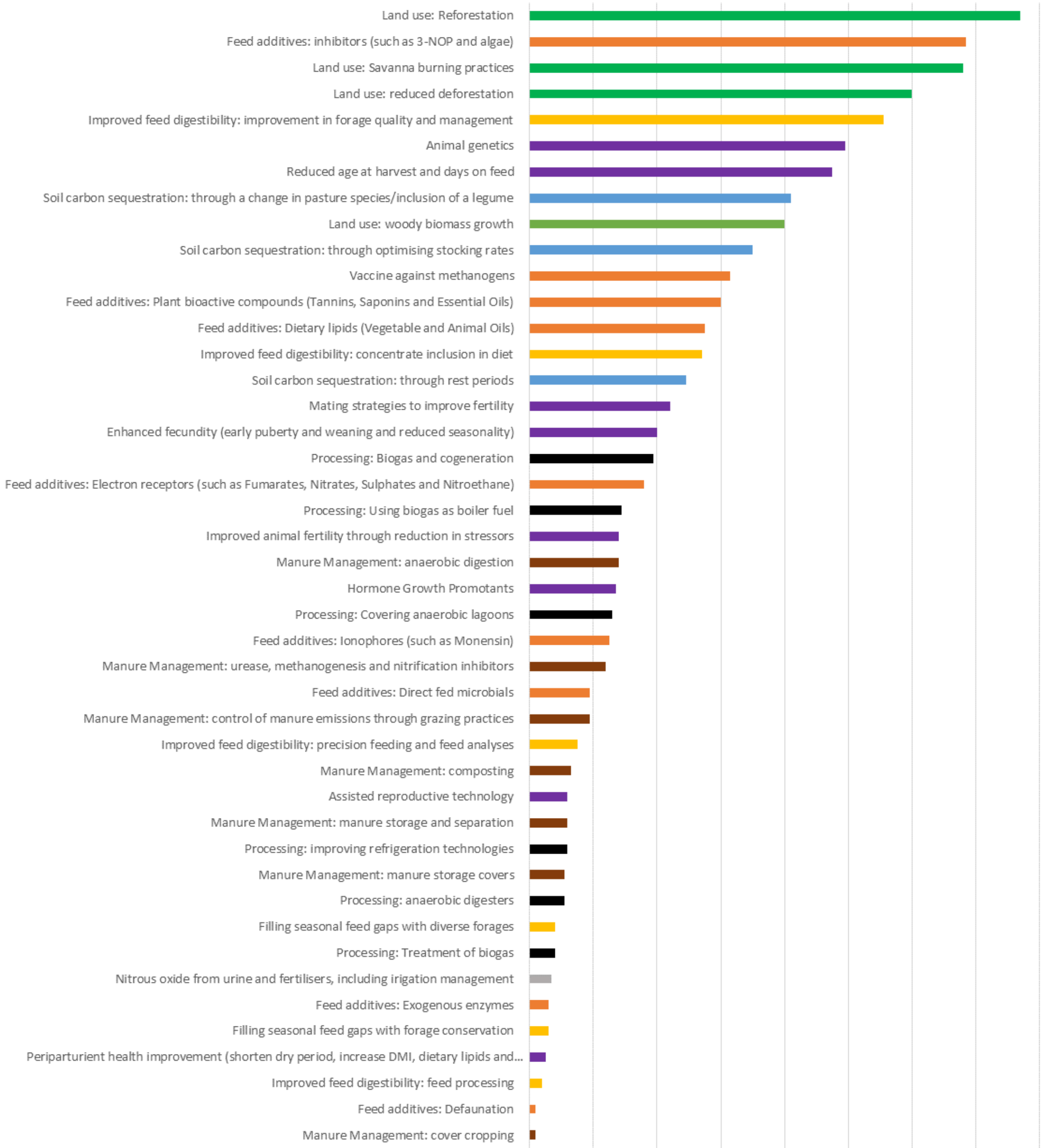

Figure A1. Ranking of all mitigation options as determined by the Delphi survey. Options with a longer bar were considered most important by survey participants.

9.2 Detailed baseline of emissions attributable to the red meat sector

Table A1. GHG emissions from the red meat industry for 2005 (baseline) and 2015 (current). Values are Mt CO_2e.

Category	Source	2005	2015
Enteric fermentation	Beef cattle Pasture	31.40	30.43
Enteric fermentation	Sheep meat	7.234	6.806
Enteric fermentation	Beef cattle Feedlot	1.389	1.569
Enteric fermentation	Goats	0.058	0.065
Manure management	Beef cattle Feedlot	0.696	0.785
Manure management	Beef cattle Pasture	0.016	0.012
Manure management	Sheep	0.002	0.002
Manure management	Goats	0.001	<0.001
Manure management	Indirect N_2O emissions - Beef cattle feedlot	0.040	0.045
Processing[A]	Sheep	0.332	0.307
Processing[A]	Beef	1.113	1.086
Energy use[B]	Feedlots (general & feed milling)	0.078	0.110
Energy use[C]	Energy use on farm – beef	0.956	0.917
Energy use[D]	Energy use on farm - sheep	0.372	0.374
Agricultural soils	Inorganic Fertilisers	0.399	0.613
Agricultural soils	Organic Fertilisers - animal waste applied to soils - beef cattle feedlot	0.075	0.084
Agricultural soils	Urine and Dung Deposited by Grazing Animals - urine - Beef cattle Pasture	1.086	1.017
Agricultural soils	Urine and Dung Deposited by Grazing Animals - urine - Goats	0.004	0.005
Agricultural soils	Urine and Dung Deposited by Grazing Animals - urine - Sheep	0.418	0.389
Agricultural soils	Urine and Dung Deposited by Grazing Animals - faeces - Beef cattle Pasture	0.555	0.537
Agricultural soils	Urine and Dung Deposited by Grazing Animals - faeces - Goats	0.002	0.002
Agricultural soils	Urine and Dung Deposited by Grazing Animals - faeces - Sheep	0.139	0.132
Agricultural soils	Crop Residue	1.602	1.673
Agricultural soils	Mineralisation due to loss of soil carbon	0.009	0.003
Agricultural soils	Cultivation of Histosols	<0.001	0.001
Agricultural soils	Atmospheric Deposition - fertiliser	0.040	0.061
Agricultural soils	Atmospheric Deposition - manure - Beef cattle feedlot	0.003	0.003
Agricultural soils	Atmospheric Deposition - manure - Beef cattle pasture	0.172	0.163
Agricultural soils	Atmospheric Deposition - manure - Goats	0.001	0.001
Agricultural soils	Atmospheric Deposition - manure - Sheep	0.059	0.055
Agricultural soils	Nitrogen Leaching and Run-Off - fertiliser	0.205	0.313
Agricultural soils	Nitrogen Leaching and Run-Off - manure - Beef cattle feedlot	0.002	0.002
Agricultural soils	Nitrogen Leaching and Run-Off - manure - Beef cattle pasture	0.428	0.334

Agricultural soils	Nitrogen Leaching and Run-Off - manure - Goats	0.001	0.001
Agricultural soils	Nitrogen Leaching and Run-Off - manure - Sheep	0.149	0.138
Agricultural soils	Nitrogen Leaching and Run-Off - crop residues	0.193	0.197
Agricultural soils	Nitrogen Leaching and Run-Off - mineralisation due to loss of soil C	0.003	<0.001
Field Burning of Agricultural Residues	Field Burning of Agricultural Residues	0.011	0.018
Liming	Liming	0.295	0.335
Urea Application	Urea Application	0.144	0.220
Forest land	Forestland remaining forest land	2.874	-0.033
Forest land	Grassland converted to forest land	-14.71	-12.47
Crop land	Cropland remaining crop land	-0.130	-0.266
Crop land	Land converted to crop land	0.338	0.240
Grassland	Grassland remaining grassland	11.09	2.514
Grassland	Land converted to grassland	75.01	29.86

All emissions are calculated based on the National GHG inventory, except for;

[A] Processing. Calculated based on emissions reported by Ridoutt *et al.* (2015)

[B] Energy use – feedlots. Calculated based on emissions reported by Wiedemann *et al.* (2017)

[C] Energy use on farm – beef. Calculated based on emissions reported by Wiedemann *et al.* (2016)

[D] Energy use on farm – sheep. Calculated based on emissions reported by Wiedemann *et al.* (2015c)