Final report

Greenhouse gas footprint of the Australian red meat production and processing sectors 2017 and 2018 updates

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Prepared by:	Dianne Mayberry Commonwealth Scientific and Industrial Research Organisation
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Meat and Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

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Abstract

This report provides an update of greenhouse gas (GHG) emissions attributed to the Australian red meat sector based on the 2018 UNFCCC Australian National GHG Inventory. The report presents GHG emissions for beef cattle, sheep meat and goats in 2018 and recalculates emissions from 2005 and 2015-2017 using current inventory data.

GHG emissions from the red meat sector in 2018 were 63.5 Mt CO_2e. The majority of these emissions are on-farm production of beef cattle, particularly enteric fermentation and vegetation management.

Total emissions from red meat have been fairly consistent between 2016, 2017 and 2018, contributing 11-12% of national emissions during this period. There was a small increase in emissions between 2017 and 2018, primarily related to a reduction in emissions removal due to reduced regrowth of forest and sparse woody vegetation.

Executive summary

Background

The red meat industry contributes to Australian national greenhouse gas (GHG) emissions. In a previous project (B.CCH.7714), we developed a method to quantify GHG emissions from red meat production based on the UNFCCC Australian National GHG Inventory. Annual updates to these calculations enable the industry to track changes in emissions attributed to red meat.

Objectives

The objectives of this project were to:

- Provide an update on the greenhouse gas footprint of the Australian red meat production (farm and feedlot) and processing sectors
- Calculate GHG footprint for Australian red meat industry in 2005 and 2015-18 using alternative Global Warming Potential (GWP) and Global Temperature Potential (GTP) metrics

Methodology

Emissions from the 2018 UNFCCC Australian National GHG Inventory were allocated to the production of beef, sheep meat and goats based on animal numbers, feed intake, volume of meat produced and resource use. Emissions from dairy and wool production were excluded.

The 2018 UNFCCC National Inventory uses GWP_{100} values of 25 for methane and 298 for nitrous oxide. Emissions from the red meat sector were estimated based on these values, and compared to calculations using GWP_{20}, GTP_{100} and GTP_{20}.

Results/key findings

GHG emissions from the red meat sector in 2018 were 63.5 Mt CO_2e; 11.8% of total national emissions. The majority of emissions are from enteric methane production, particularly from grazing beef cattle. There are also considerable emissions from grazing lands related to vegetation management.

Emissions from the red meat industry have decreased since 2005 (135.8 Mt CO_2e, 22% total national emissions), and have remained fairly constant between 2016 and 2018. A small increase in emissions between 2017 and 2018 is related to reduced regrowth of forests and sparse woody vegetation.

Benefits to industry

The results presented in this report enable the red meat industry to identify major sources of emissions, monitor changes in emissions, and prioritise activities to reduce emissions as part of a CN30 program.

Future research and recommendations

The report suggests opportunities to improve the accuracy of these calculations, particularly the opportunity to work with the Department of Industry, Science, Energy and Resources to report land use emissions on a spatial basis.

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1. Background

The red meat industry is an important contributor to the national economy and international markets. It also contributes to Australian greenhouse gas (GHG) emissions. A focus on reducing GHG emissions from this sector presents an opportunity for the sustainability of the industry, and to enable Australia to meet its commitments set under the Paris climate agreement. In a previous project (B.CCH.7714 Greenhouse Gas mitigation potential of the Australian red meat production and processing sectors) we developed a method to quantify GHG emissions from red meat production based on the Australian National GHG Inventory (Mayberry et al. 2018). Annual updates to the red meat GHG footprint enable the industry to monitor changes in emissions.

This current project was conducted to update the GHG footprint of the Australian red meat industry using data from the 2017 and 2018 national inventories.

2. Objectives

The objectives of this project were to:

- Provide an update on the greenhouse gas footprint of the Australian red meat production (farm and feedlot) and processing sectors, including:
  - Calculated emissions from the red meat sector in 2017 and 2018
  - Revised emissions from 2005, 2015 and 2016 based on current inventory data
- Calculate GHG footprint for Australian red meat industry in 2005 and 2015-18 using alternative GWP and GTP metrics
- Participate in production of a short (5 minute) video summarising the findings of the update. The video will be produced by MLA.

The first project milestone was completed following the submission of a report detailing emissions from the red meat sector in 2017 (May 2020). This final report provides details on emissions from the red meat sector using data from the 2018 inventory.

Covid-19 restrictions prevented the production of the video to summarise the report findings. In lieu of this activity, this report includes a section summarising key messages for industry.

3. Methodology

3.1 Greenhouse gas emissions from the Australian red meat sector

This report provides an update of GHG emissions from the Australian red meat sector based on the 2018 United Nations Framework Convention on Climate Change (UNFCCC) Australian National Inventory (DISER 2021). The Department of Industry, Science, Energy and Resources (DISER) review and update activity data and the inventory methodology each year, and changes are applied retrospectively to past inventories. Thus, this report supersedes previous project reports describing the distribution of GHG emissions from the red meat sector using this method. The National Inventory reports emissions in gigagrams (Gg), where 1 Gg = 1 million kg. For ease of reporting, values included here are reported as the more commonly used megatonne (Mt), where 1 Mt = 1000 Gg or 1 million metric tonnes.

Emissions from the 2018 National Inventory were allocated to the red meat sector based on animal numbers, feed intake, meat production and resource use as described by Mayberry et al. (2018) and outlined in the appendix (section 8.2). This analysis is not a life cycle assessment. Our calculations include the following emissions from beef, sheep meat and goat production:

- animal processes (enteric methane, manure)
- production of livestock feed (pastures for grazing livestock, grain used in feedlot rations)
- land management practices (e.g. clearing, reclearing and regrowth of native vegetation)
- electricity and fuel used on farm, in feedlots, and during processing

Although some dairy animals are consumed as red meat, we consider these animals to be by-products of the dairy industry, and emissions from dairy were excluded wherever possible. Emissions from sheep were attributed to either meat or wool based on the protein mass allocation method (Wiedemann et al. 2015), and emissions from wool were excluded. The analysis also excludes emissions associated with domestic transport of livestock, live export animals after they leave Australia, cropland used to produce grain fed to livestock outside of feedlots (e.g. confinement fed sheep), manufacture and transport of feed (e.g. hay and silage), and manufacture and transport of fertiliser.

3.2 Alternative GWP and GTP metrics

GHG gas emissions from the red meat sector include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). CH_4 and N_2O are typically expressed as CO_2-equivalents (CO_2e), which describes the amount of CO_2 that would result in an equivalent climate impact (Lynch 2019). There are several different CO_2e metrics that can be expressed over different timescales; usually 20 or 100 years (Table 1). Global Warming Potential (GWP) is the most widespread CO_2e and is a measure of how much energy a greenhouse gas traps in the atmosphere in a given time period relative to CO_2. The most common alternative metric, Global Temperature Potential (GTP), is a measure of global temperature change at the end of a given time period relative to CO_2.

Table 1. Global Warming Potential (GWP) and Global Temperature change Potential (GTP) of methane and nitrous oxide (Myhre et al. 2013). Current GWP values used in the Australian National GHG Inventory are highlighted with shading.

	Greenhouse gas	
	CH_4	**N_2O**
GWP_{100} – current	25	298
GWP_{100} – potential future values	28	265
GWP_{20}	84	264
GTP_{20}	67	277
GTP_{100}	4	234

The 2018 UNFCCC Australian National GHG Inventory uses GWP_{100} values of 25 for CH_4 and 298 for N_2O (DISER 2020b). It is anticipated that these values will be revised to 28 for CH_4 and 265 for N_2O in future releases.

In the main analysis described above, we used the current GWP values to be consistent with the 2018 National GHG Inventory. In addition, we calculated GHG emissions from the red meat sector using the alternative GWP and GTP values listed in Table 1.

4. Results

4.1 Greenhouse gas emissions from the Australian red meat sector

Total GHG emissions attributed to the red meat sector in 2018 were 63.5 Mt CO_2e, accounting for 11.8% of total national emissions (Table 2). The majority of emissions are from on-farm sources (Table 3); enteric fermentation, particularly from grazing beef cattle, and land use change associated with red meat producing properties.

Annual emissions from 2018 are higher than 2017, but similar to 2016 (Table 2). The increase in emissions between 2017 and 2018 is driven by emissions from land use, land use change and forestry (LULUCF). Although the area of both sparse woody vegetation and forest cleared has decreased over the past three years, the area of regrowth is also smaller (Fig. 1 and 2), leading to a decrease in carbon storage in vegetation. These changes are driven by a combination of land management practices and climate, with a large proportion of land clearing attributable to grazing industries (DISER 2020c).

Table 2. Greenhouse gas emissions (Mt CO_2e) from the Australian red meat sector by source. Values in italics are sector sub totals.

Source of emissions	2005	2015	2016	2017	2018
Agriculture	*51.60*	*49.16*	*48.50*	*50.10*	*50.48*
Enteric fermentation	41.70	39.03	38.38	39.72	40.05
Agricultural soils	5.51	5.54	5.64	5.74	5.72
Manure management	4.00	4.11	4.00	4.10	4.18
Liming & urea	0.39	0.48	0.48	0.53	0.51
Field burning of agricultural residues	0.01	0.01	0.01	0.02	0.01
Land use, land use change & forestry	*81.31*	*23.77*	*12.11*	*6.89*	*10.43*
Cropland	0.21	0.06	-0.06	-0.10	-0.06
Forest land	-10.86	-18.48	-26.65	-28.59	-24.08
Grassland	91.96	42.19	38.82	35.59	34.56
Energy	*2.92*	*2.76*	*2.53*	*2.58*	*2.64*
Total red meat emissions	***135.84***	***75.70***	***63.14***	***59.58***	***63.54***
Total national emissions	617.22	538.82	526.15	529.49	537.45
Proportion total national emissions (%)	22.0	14.1	12.0	11.3	11.8

Table 3. Greenhouse gas emissions (Mt CO_2e) from farm, feedlot, and processing sectors

Source of emissions	2005	2015	2016	2017	2018
Farm	132.43	72.24	59.99	56.41	60.17
Feedlot	1.96	2.08	1.98	2.00	2.16
Processing	1.45	1.37	1.16	1.16	1.22

Figure 1. Change in area of sparse woody vegetation between 1990 and 2018. Data is from the Australian National Greenhouse Gas Inventory activity tables. Area is total national area of vegetation gains and losses.

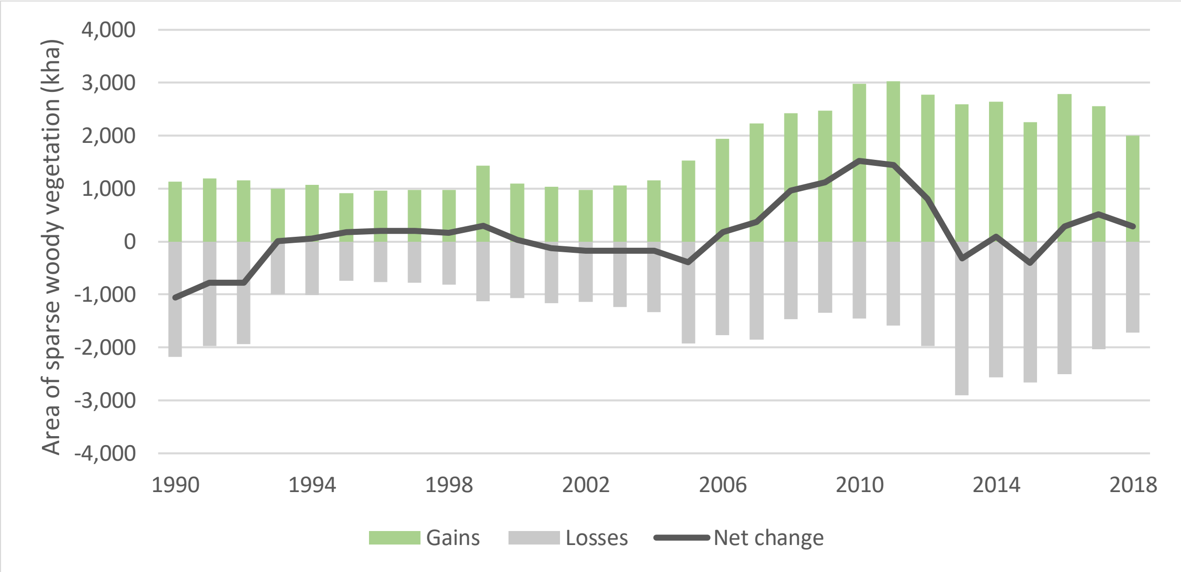
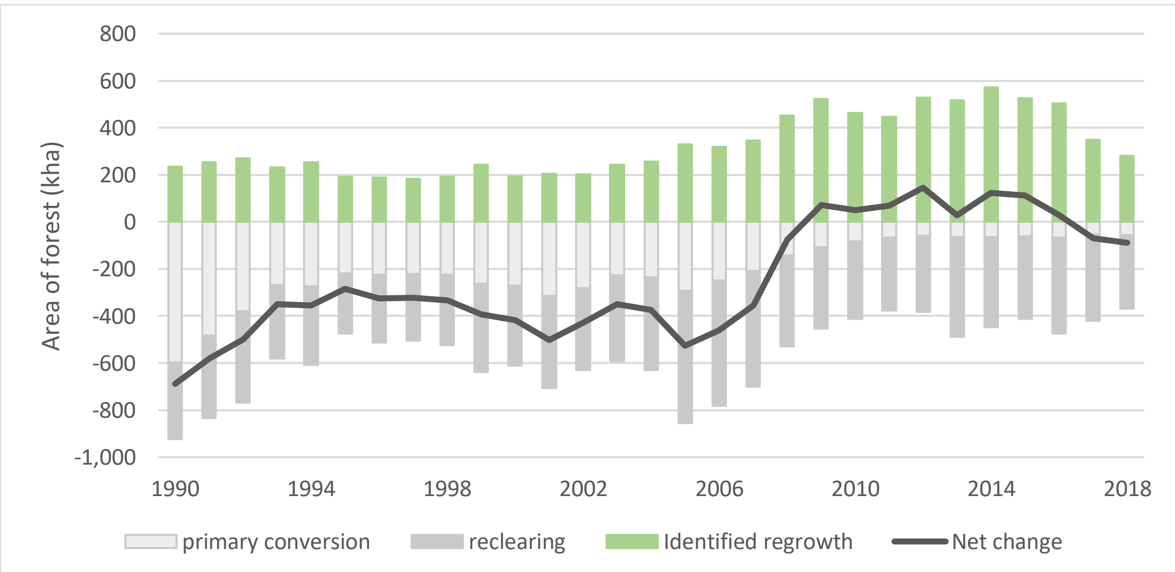


Figure 2. Change in area of forest between 1990 and 2018. Land clearing is from a combination of primary conversion and reclearing. Data is from the Australian National Greenhouse Gas inventory activity tables. Area is total national area of vegetation gains and losses.



As with previous years, beef cattle contribute the majority of emissions (57.3 Mt CO_2e), with smaller contributions from sheep meat (6.2 Mt CO_2e) and goats (0.07 Mt CO2e; Table 4). Emissions from both cattle and sheep meat increased between 2017 and 2018 due to changes in emissions from LULUCF. In addition, emissions from enteric fermentation and manure in cattle increased with the size of the cattle herd (Table 5). While the total number of sheep was lower in 2018 than 2017, meat production was higher and wool yield was lower, meaning a greater proportion of emissions from sheep were attributed to meat production.

Table 4. Contribution of beef cattle, sheep meat and goats to greenhouse gas emissions (Mt CO_2e) from the Australian red meat sector.

Source of emissions	2005	2015	2016	2017	2018
Cattle	118.04	65.38	55.79	54.42	57.29
Sheep meat	17.73	10.24	7.28	5.09	6.19
Goats	0.07	0.08	0.07	0.07	0.07

Table 5. Livestock numbers and red meat production in 2005, 2015-2018. Data is from the Australian National Greenhouse Gas Inventory activity tables and ABS annual statistics.

	2005	2015	2016	2017	2018
Beef					
Total beef cattle[1] (million head)	25.2	24.6	24.3	24.9	25.1
Annual feedlot turnoff (million annual equivalents[2])	0.82	0.93	0.94	0.94	1.03
Beef produced (million tonnes)	2.06	2.51	2.10	2.13	2.29
Sheep					
Total sheep (million head)	100.7	70.9	70.9	75.7	74.1
Lamb & mutton produced (million tonnes)	0.62	0.71	0.69	0.70	0.74
Wool produced (greasy)	0.46	0.36	0.36	0.38	0.36

[1] excludes dairy cattle
[2] number of animals adjusted for days on feed

4.2 Changes to the National Greenhouse Gas Inventory

DISER recalculates Australian GHG emissions each year in response to recommendations and updated methods from the Intergovernmental Panel on Climate Change (IPCC) and UNFCCC (e.g. changes to emissions factors) and revised activity data (e.g. livestock populations or mapping of land use). Revisions to the UNFCCC Australian National GHG Inventory methods and activity data have affected previously published estimates of total national GHG emissions and emissions attributed to the red meat sector.

Changes of most relevance when considering emissions from the red meat sector are:

- Changes to calculation of emissions from manure management, contributing to an increase in emissions from grazing livestock (DISER 2020b). The biggest change is that the inventory now accounts for methane production from manure inputs in agricultural ponds (Grinham et al. 2018; Ollivier et al. 2019). The method assumes that 5% of beef cattle and sheep manure is deposited in ponds. There have been smaller changes in emissions due to revised estimates for the fraction of N volatilised, fraction of N lost through leaching, and N_2O emissions factors for leaching and runoff.

- Spatial simulation of fires using FullCAM (DISER 2020c). Carbon stock changes from the combustion and subsequent recovery of biomass from wildfire is now included in forest land grazed by livestock, leading to greater inter-annual variability in reported emissions. There are higher carbon stock losses in years with higher than average area of wildfire, and equivalent increases in carbon stock gains during the recovery period.
- Updated spatial observations, particularly relating to the area of forest land (DISER 2020c). Observations on land clearing have been updated based on state agency data. This has led to a reduction in emissions reported from grasslands.
- Revised weather and climate data to provide improved interpolation of data between known data locations (DISER 2020c). This has led to an increase in modelled forest growth and net sequestration in forest land.
- Improvements in the calibration of the FullCAM model, specifically related to the regeneration of native vegetation (DISER 2020c).

The inventory reports also flag future potential changes to the national inventory that will impact estimation of greenhouse gas emissions from the red meat sector (DISER 2020b). These include:

- Review of feed, animal, and herd characteristics - more accurate assumptions of liveweight and feed quality, and better methods to better reflect emissions related to milk intake of pre-weaned animals
- Improved methods for estimating production of enteric methane from sheep based on data collected under the Reducing Emissions from Livestock Research Program, funded by the Australian Government Department of Agriculture, Fisheries and Forestry.
- Review of emissions factors for N_2O from manure in feedlots based on research from Redding et al. (2015)
- Improvements to the method to estimate methane emissions from manure inputs into agricultural ponds

4.3 Alternative CO_2e metrics

A change in GWP values from 25 to 28 for CH_4 and 298 to 265 for N_2O (from current to potential GWP_{100} values as per Table 1) would increase the reported total national GHG emissions and the estimated GHG emissions from the red meat sector (Table 6). However, the increase in the proportion of national emissions attributed to red meat production would only be small.

Table 6. GHG emissions in 2005 and 2017 calculated using different CO_2e metrics

	Total national emissions (Mt CO_2e)		Emissions from red meat (Mt CO_2e)		% national emissions from red meat	
	2005	2018	2005	2018	2005	2018
GWP_{100} – current	617.2	537.45	135.8	63.5	22.0	11.8
GWP_{100} – future	629.2	549.9	141.4	68.7	22.5	12.5
GWP_{20}	919.3	830.5	263.4	183.6	28.6	22.1
GTP_{100}	502.3	427.1	88.1	18.5	17.5	3.4
GTP_{20}	832.3	746.3	226.7	149.1	27.2	20.0

Using GTP instead of GWP would reduce the proportion of emissions associated with the red meat sector. Across both GWP and GTP, using a shorter time-period (20 rather than 100 years) increases both total national emissions and the proportion of emissions from red meat.

A more detailed analysis will be provided in the Assessment of Climate Accounting Metrics for the Australian Red Meat Industry (B.CCH.2117), due for completion later this year.

4.4 Input into annual update communications

Why does DISER update the National GHG Inventory each year?

DISER compiles and submits the Australian National GHG Inventory (DISER 2021) and a Report on emissions (DISER 2020b, 2020c, 2020d) to the UNFCCC each year on behalf of the Australian Government and in accordance with international guidelines (IPCC 2006). The Report contains estimates of national GHG emissions from 1990 onwards, and details of how emissions are calculated (data sources, assumptions, methodologies). The use of a common method and reporting framework enables comparison of emissions and removals between countries and facilitates national and international reviews.

The methods used to estimate emissions in Australia and other countries are continuously refined as new information emerges and international practice evolves. This ensures that the accuracy of GHG emissions reporting is always improving. When better methods and data become available, they need to be applied to all years (1990 onwards) so there is internal consistency in the inventory.

What does this mean for how emissions from the red meat sector are reported?

Because improvements to the methods and data used to estimate GHG emissions are applied to all years, national GHG emissions reported for previous years may change with each new release of the national inventory. Changes may impact all sectors of the inventory, including emissions attributed to red meat production.

For example, Charmley et al. (2016) analysed enteric methane production from cattle using data collected using open-circuit respiration chambers. They found that methane emissions from cattle in Australia fed forage-based diets were likely over-estimated by the methods previously used in the national inventory. The updated equations were included in the national inventory from 2016 onwards (DISER 2020), and previously reported estimates of enteric methane from cattle were reduced.

The 2018 inventory (data from this report) includes new methods that account for emissions from manure in agricultural ponds (e.g. farm dams), changes to equations used to estimate emissions from N leaching and runoff, improved spatial observations of how land is used, and improvements in the models used to estimate emissions from wildfire and growth of native vegetation (section 4.2 of this report).

What emissions are attributed to red meat production in this report?

Emissions from red meat included in this report include:

- Enteric fermentation: CH_4 produced by beef cattle, sheep, and goats as a by-product of the digestive process
- Manure management: emissions from manure in intensive systems (e.g. feedlots) where large amounts of manure accumulate and are stockpiled, and the breakdown of waste in agricultural ponds (e.g. stock dams)
- Agriculture soils: N_2O from microbial and chemical transformations of N fertilisers, animal waste (deposited directly during grazing or as an organic fertiliser), crop residues and cultivation of organic soils.
- Field burning of agricultural (crop) residues
- Application of limestone, dolomite, and urea to soil
- Vegetation management: emissions from clearing or reclearing of vegetation, and carbon storage in regrowth of forests and woody vegetation
- Emissions from wildfire, including savanna burning
- Energy required for processing of red meat and some on-farm activities

Emissions from enteric fermentation and manure are reported directly by the National GHG Inventory for beef cattle in feedlots, beef cattle grazing pasture, sheep, and goats. Emissions from pastures, grasslands and forest land grazed by livestock are attributed to red meat based on the relative consumption of beef cattle, sheep, and dairy cattle. Emissions from cropland are attributed to red meat based on an estimate of the area of cropland required to supply grain to cattle in feedlots.

Sheep produce both meat and wool. How are these emissions separated?

The aim of this project was to report on emissions associated with red meat production, so it was necessary to allocate emissions from sheep between meat and wool. Emissions from meat and wool were estimated based on the national reported volume of lamb, mutton, live export sheep and greasy wool produced. Using the method of Wiedemann et al. (2015), the amount of protein produced as meat and wool was summed for each year, and the proportion of protein in meat was calculated. This proportion was applied to the total amount of emissions from sheep to estimate emissions associated with meat production.

The relative proportions of meat and wool produced each year vary, depending on factors such as sheep breeds, type of production system, and seasonal conditions, so the relative proportion of emissions allocated to meat and wool varies.

What are the main sources of emissions from red meat production?

In Australia, the main sources of GHG emissions from red meat production are enteric fermentation, and vegetation management. Enteric fermentation refers to CH_4 that is produced as a by-product of digestion, and the total amount produced is directly related to the number of ruminant livestock. Emissions from vegetation management result from the clearing and re-clearing of woody vegetation.

How have emissions from the red meat sector changed between 2005 and 2018?

Emissions from red meat production in 2018 (63.5 Mt CO_2e) are less than half of what they were in 2005 (135.8 Mt CO_2e). This reduction in emissions was driven by changes in vegetation management, in particular, a reduction in the area of forest land which was cleared or re-cleared for grazing (see Fig 2). There has also been an increase in carbon storage in regrowth of woody vegetation on previously cleared land.

There was also a reduction in emissions from enteric fermentation during this period as the number of sheep was reduced.

How do emissions from the red meat sector compare to other sources of emissions in Australia?

In 2018, emissions from red meat were estimated to be 63.5 Mt CO_2e. By comparison, emissions from public electricity and heat production were 183.2 Mt CO_2e, and emissions from domestic transport were 100.8 Mt CO_2e.

While emission from red meat production have decreased since 2005, emissions from energy and industrial processes have increased.

5. Conclusion

5.1 Key findings

This report shows that emissions from the red meat industry have decreased since 2005 and remained relatively stable in 2016, 2017 and 2018. Reductions in emissions during since 2005 are driven by changes in vegetation management – there has been a reduction in land cleared and re-cleared for grazing, and an increase in regrowth on previously cleared land. Small changes in emissions from animal processes (enteric fermentation and manure) have also occurred in response to changing animal numbers.

Further significant decreases in GHG emissions will not be achieved without specific activities that target the main sources of GHG emissions – enteric fermentation, especially from grazing beef cattle, and vegetation management. However, it is important to note that the original report quantifying GHG emissions from the red meat sector was published in 2018, and the impact of industry activities to reduce emissions following that report would not be captured in the current inventory.

5.2 Benefits to industry

Annual reporting of the GHG emissions from red meat production enable MLA, and the industry more broadly, to identify the main sources of emissions, prioritise areas for further RD&E, and monitor changes over time.

6. Future research and recommendations

As part of the Climate Accounting Metrics Project (B.CCH.2117), CSIRO is working with DISER to improve the reporting of LULUCF emissions associated with red meat production. The revised method will use a spatial approach to report emissions from grassland and forest land based on national livestock density maps. This will provide more accurate reporting of land use emissions. It may also allow better reporting of specific emissions of interest to the red meat sector such as savanna burning.

Links to the Climate Research Strategy for Primary Industries (CRSPI)-funded project on a Common Accounting Framework would provide opportunities for a consistent approach across the agricultural industries. This would ensure that all agricultural and land use emissions were accounted for and attributed to the appropriate industries, whilst also ensuring that there is no double-accounting. This is particularly important where boundaries between sectors are not always clear, for example, the allocation of emissions in sheep between meat and wool production.

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8. Appendix

8.1 List of commonly used terms and acronyms

CO_2e	Carbon dioxide equivalent. A common unit for comparing different greenhouse gases.
DISER	Department of Industry, Science, Energy and Resources. The Federal Department responsible for the Australian National Greenhouse Gas inventory.
Direct emissions	Greenhouse gas emissions released directly from an activity. E.g. methane from enteric fermentation, or methane and nitrous oxide from decomposition of manure.
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.
FullCAM	Full Carbon Accounting Model. FullCAM is a calculation tool for modelling Australia's greenhouse gas emissions from the land sector. It is used in Australia's National Greenhouse Gas Accounts for the land use, land use change and forestry sectors, and to generate abatement estimates for vegetation methods under the Emissions Reduction Fund.
Grassland	Rangelands and permanent pastures. Includes areas of sparse woody vegetation that do not meet the definition of forest.
GHG	Greenhouse gas. Includes carbon dioxide, methane and nitrous oxide.
GTP	Global Temperature Potential. A measure of global temperature change at the end of a given time period (usually 20 or 100 years) relative to carbon dioxide.
GWP	Global Warming Potential. A measure of how much energy a greenhouse gas traps in the atmosphere in a given time period (usually 20 or 100 years) relative to carbon dioxide.
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.
IPCC	The Intergovernmental Panel on Climate Change. The IPCC is the United Nations body for assessing the science related to climate change.
LULUCF	Land use, land use change and forestry. A sector of the National Inventory, which includes emissions from cropland, forest land and grassland. Land use change is a permanent change in land use, e.g. from forest land to grassland.
Leaching	Process by which soluble substances (e.g. nitrogen) are washed from soil or waste.
Mt	Mega tonne. Equivalent to 1 million metric tonnes.
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

8.2 Detailed methods for allocating emissions from the National Greenhouse Gas Inventory to red meat production

Emissions source	Allocation to red meat
Agriculture	
Enteric fermentation	All emissions from beef cattle feedlot, beef cattle pasture and goats were reported directly from the national inventory. Emissions from sheep were corrected for meat-wool co-production (Wiedemann et al. 2015). Emissions from all other livestock were excluded.
Manure management	All emissions from beef cattle feedlot, beef cattle pasture and goats were reported directly from the national inventory. Emissions from sheep were corrected for meat-wool co-production (Wiedemann et al. 2015). Emissions from all other were livestock excluded.
Agricultural soils	Direct emissions from animal waste applied to soils (beef cattle – feedlot) and direct and indirect emissions from urine and dung from beef cattle and goats were reported directly from the national inventory. Emissions from sheep were corrected for meat-wool co-production (Wiedemann et al. 2015). Emissions from all other livestock were excluded. Direct and indirect emissions from cropland were included based on the proportion of cropland required to supply feedlots. Direct and indirect emissions from irrigated pasture were calculated based on the proportion of irrigated pasture used for beef and sheep meat production (ABS 2019). The area of irrigated pasture used for sheep production was correct for meat-wool co-production (Wiedemann et al. 2015). The area of non-irrigated pasture was attributed to beef or sheep meat based on relative feed intake.
Field burning of agricultural residues	Emissions were included based on the proportion of cropland required to supply feedlots (Wiedemann et al. 2017), as described for *agricultural soils*.
Liming	The proportion of emissions attributed to red meat was calculated based on the proportion of lime and dolomite used for beef and sheep farming compared to other agricultural sectors (ABS 2014). Volume of lime used for sheep farming was corrected for meat-wool co-production (Wiedemann et al. 2015).
Urea application	The proportion of emissions attributed to red meat was calculated based on the proportion of urea fertiliser used for beef and sheep farming compared to other agricultural sectors (ABS 2014). Volume of urea fertiliser used for sheep farming was corrected for meat-wool co-production (Wiedemann et al. 2015).

LULUCF	
Forest land	Emissions from forest land remaining forest land were calculated based on area of forest land available for grazing (excludes plantations, harvested forests, areas protected for biodiversity and conservation (ABRES 2017)).
Crop land	Emissions from crop land remaining crop land and forest land converted to cropland were attributed to the red meat sector based on the proportion of crop land required to supply feedlots (Wiedemann et al. 2017).
Grassland	The proportion of emissions from grassland remaining grassland was allocated to the red meat sector based on relative feed intake of beef cattle, dairy cattle, and sheep.

Energy	
Energy	General energy use in feedlots was calculated based on energy required per 1000-head day (Wiedemann et al. 2017), number of cattle in feedlots and days on feed (DISER 2020a). Energy used for feed milling and delivery was calculated based on energy required per tonne of feed (Wiedemann et al. 2017) and feed intake. On-farm energy use for beef cattle was calculated based on tonnes of dry matter intake (Wiedemann et al. 2016) , numbers of animals and feed intake. On-farm energy use for sheep was calculated based on energy per 1000 ewes joined (Wiedemann et al. 2015) and number of breeding ewes, then attributed to either meat or wool production based on the protein mass allocation method (Wiedemann et al. 2015). Greenhouse gas emissions from energy use in feedlots and on-farm were calculated based on energy content and emissions factors of electricity, gas, petrol and diesel (DoEE 2017). Energy use from processing was calculated based on reported emissions per tonne red meat and the proportion of emissions attributed to energy consumption (All Energy Pty Ltd 2021; Ridoutt et al. 2015), and volume of meat produced (ABS 2020). The method accounts for improvements in processing efficiency captured in the Red Meat Processing Sector Environmental Performance Reviews conducted every 5 years.

Co-production of meat and wool from sheep

Emissions from sheep were corrected for meat-wool co-production using the method of (Wiedemann et al. 2015), and based on the volume of liveweight and wool sold each year. Liveweight was estimated based on volume of mutton and lamb produced, corrected for dressing percentage, and gross weight of live export sheep (ABS 2020). Greasy wool yield is reported by ABARES (2018).

The volume of liveweight and wool produced each year varies due to seasonal conditions. In 2018, 60% of emissions from sheep were allocated to meat production.

Attribution of cropland emissions to red meat

The area of cropland used to support feedlot cattle production was estimated based on Wiedemann et al. (2017), who report average area of cropland per kg liveweight gain for cattle in Australian feedlots.

Area of cropland occupation was calculated based on the number of cattle in feedlots, days on feed and average daily liveweight gain (DISER 2020a; DISER 2020b). This was divided by the total cropland area (DISER 2020c) to provide the proportion of cropland that contributes to feedlot cattle production. The proportion was then applied to all cropland emissions in the inventory to estimate cropland emissions attributable to red meat production.

The number of cattle in feedlots and total cropland area varies each year. In 2018, we estimated that 3.8% of emissions from cropland were attributable to red meat production.

Proportion of pasture used for beef and sheep-meat production

The proportion of emissions from irrigated pasture allocated to red meat is calculated based on the proportion of area used. The ABS reports time-series data for the area of irrigated land used for various activities including dairy production, production from meat cattle, and production from sheep and other livestock (ABS 2019). The area of irrigated pasture used for *sheep and other livestock* is not able to be further disaggregated, and the entire area is allocated to sheep in our calculation, then corrected for meat-wool co-production as described above. While this likely overestimates the area of irrigated pasture used for sheep production, the total area, and therefore emissions included in the red meat inventory are small.

The proportion of emissions from non-irrigated pasture allocated to red meat is calculated based on feed intake. The time-series spreadsheets from the National Inventory estimated total feed intake for dairy cattle, beef – pasture and sheep. While there is no way to calculate the proportion of intake that comes from non-irrigated pasture, it is assumed that most dairy pastures are irrigated, and that pasture (rather than hay or grain), forms the majority of grazing beef cattle and sheep diets.

8.3 Detailed emissions breakdown for beef and sheep-meat in 2018

Emissions source	**Beef cattle**	**Sheep meat**
Agriculture	*41.07*	*9.34*
Enteric fermentation	32.48	7.52
Agricultural soils	4.42	1.30
Manure management	3.80	0.38
Other emissions	0.37	0.15
Land use, land use change & forestry	*14.92*	*-4.49*
Cropland	-0.06	
Forest land	-17.66	-6.41
Grassland	32.64	1.92
Energy	*1.30*	*1.33*
TOTAL	**57.29**	**6.19**