Final report

Greenhouse Gas Footprint of the Australian Red Meat Production and Processing Sectors 2019

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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 2019 UNFCCC Australian National GHG Inventory. The report presents GHG emissions for beef cattle, sheep meat and goats in 2019 and recalculates emissions from 2005 and 2015-2018 using current inventory data.

GHG emissions from the red meat sector in 2019 were 54.6 Mt CO_2e. The majority of these emissions were on-farm production of beef cattle, particularly enteric fermentation and vegetation management.

Total emissions from red meat have been fairly consistent between 2016 – 2019, contributing 10-12% of national emissions during this period. Emissions have decreased by almost 60% since 2005, primarily due to a reduction in emissions associated with vegetation management.

Executive summary

Background

The red meat industry contributes to Australia's national greenhouse gas (GHG) emissions. In a previous project (B.CCH.7714), a method was developed 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

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 2019
- Revised emissions from 2005, 2015, 2016, 2017 and 2018 based on current inventory data

Calculate GHG footprint for Australian red meat industry in 2005 and 2015-2019 using alternative GWP and GTP metrics (GWP_{20}, GWP_{100}, GTP_{20}, GTP_{100}).

Methodology

Emissions from the 2019 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.

Results/key findings

Greenhouse gas emissions from the red meat industry in 2019 were 54.6 Mt CO_2-e, a decrease of almost 60% since 2005, when annual emissions were 133.4 Mt CO_2-e. The majority of emissions were associated with enteric fermentation and vegetation management. The reduction in emissions since 2005 is due a reduction in the clearing of 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.

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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) a method was developed 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 2019 national inventories.

2. Objectives

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 2019
- Revised emissions from 2005, 2015, 2016, 2017 and 2018 based on current inventory data

Calculate GHG footprint for Australian red meat industry in 2005 and 2015-2019 using alternative GWP and GTP metrics (GWP_{20}, GWP_{100}, GTP_{20}, GTP_{100}).

3. Methodology

3.1 Scope of reporting

This report provides an update of GHG emissions from the Australian red meat sector based on the 2019 United Nations Framework Convention on Climate Change (UNFCCC) Australian National Inventory (DISER 2021a, b). 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 (Appendix 8.2). 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 2019 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 Appendix 8.3. This analysis is not a life cycle assessment, and emissions are those generated during a single year of livestock production. Emissions allocated to the red meat sector include:

- Enteric fermentation: methane (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: nitrous oxide (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 histosols (peaty 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 were reported directly by the National GHG Inventory for beef cattle in feedlots, beef cattle grazing pasture, sheep, and goats. For cattle and sheep, these emissions were estimated using Tier 2 methods (Tier 3 for feedlot cattle manure) and emissions factors specific to Australian production systems. For goats, these emissions were estimated using Tier 1 methods and generic IPCC emissions factors, so are less accurate. Emissions from land grazed by livestock were attributed to red meat based on the relative feed intake of beef cattle, sheep, and dairy cattle. There is not sufficient data available to estimate emissions from land grazed by goats. Emissions from cropland were attributed to red meat based on an estimate of the area of cropland required to supply grain to cattle in feedlots.

Emissions from dairy cattle and wool production were not included. Although some dairy animals are consumed as red meat, these were considered to be by-products of the dairy industry. 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. This analysis also excluded emissions associated with domestic transport of livestock (e.g. between farms, feedlots, abattoirs or ports), 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. The emissions generated from these activities are expected to be small compared to emissions from enteric methane and land use, but methods can be developed to estimate their contribution to the industry total.

3.2 Emissions factors

GHG emissions from the red meat sector include carbon dioxide (CO_2), CH_4 and N_2O. CH_4 and N_2O are often expressed as CO_2-equivalents (CO_2-e), which describes the amount of CO_2 that would result in an equivalent climate impact (Lynch 2019). There are several different CO_2-e metrics that can be expressed over different timescales; usually 20 or 100 years (Table 1). Global Warming Potential (GWP) is the most widely used climate metric 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 change 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 over 20 and 100-year periods

Emissions metric	Assessment report	Greenhouse gas	
		CH_4	N_2O
GWP_{100}	AR4	25	298
GWP_{100}	AR5	28	265
GWP_{20}	AR4	72	289
GWP_{20}	AR5	84	264
GTP_{100}	AR5	4	234
GTP_{20}	AR5	67	277

The 2019 UNFCCC National Inventory Report reported emissions as carbon dioxide equivalents (CO_2-e) using the 100-year Global Warming Potentials (GWP_{100}) contained in the IPCC Fourth Assessment Report (AR4, IPCC 2007). GWP_{100} values from the IPCC Fifth Assessment Report (AR5, Myhre et al. 2013) will be used by the National Inventory from 2020-21 (Clean Energy Regulator 2021). The AR5 GWP_{100} values are also used to track Australia's progress towards targets set as part of the Paris Agreement, and these are the values reported in the online Australian Greenhouse Emissions Information System (ageis).

GWP_{20} values also differ between AR4 and AR5. The concept of GTPs was introduced in AR4, but values were not provided. GTP_{20} and GTP_{100} values reported here are from AR5.

Values in this report are based on the AR4 GWP_{100} CO_2-e values for consistency with the National Inventory Report.

4. Results

4.1 Greenhouse gas emissions from the Australian red meat sector

Total GHG emissions attributed to the red meat sector in 2019 were 54.6 Mt CO_2-e, accounting for 10.7% of total national emissions (Table 2). The majority of these emissions are associated with grazing livestock (Table 3) especially cattle (Table 4), with enteric fermentation and land use change the biggest contributors.

Annual emissions have decreased by 9.4 Mt CO_2-e since 2018, with the reduction driven by a decrease in emissions from grasslands. This reduction in emissions is associated with a reduction in the area of sparse woody vegetation and forest cleared (Figure 1 and 2). There has also been a small reduction in methane emissions from enteric fermentation associated with a decrease in cattle and sheep numbers (Table 5).

The reduction in annual emissions since 2005 is driven by a reduction in the national sheep herd (Table 5) and the area of land cleared for grazing (Figure 1 and 2).

Table 2.Greenhouse gas emissions (Mt CO_2-e) from the Australian red meat sector by source. Values in italics are sector sub totals.

Source of emissions	2005	2015	2016	2017	2018	2019
Agriculture	*51.20*	*48.70*	*48.04*	*49.64*	*49.98*	*47.82*
Enteric fermentation	41.70	39.03	38.38	39.72	40.05	38.14
Agricultural soils	5.52	5.54	5.64	5.74	5.72	5.61
Manure management	3.59	3.65	3.54	3.64	3.69	3.56
Liming & urea	0.39	0.48	0.48	0.53	0.51	0.50
Field burning of agricultural residues	0.01	0.01	0.01	0.02	0.01	0.01

Land use, land use change & forestry	*79.24*	*19.40*	*6.92*	*0.05*	*11.34*	*4.11*
Cropland	0.31	0.02	-0.16	-0.16	-0.12	-0.14
Forest land	-11.90	-21.62	-29.08	-31.21	-28.01	-20.87
Grassland	90.82	40.99	36.16	31.42	39.47	25.12
Energy	*2.92*	*2.76*	*2.53*	*2.58*	*2.64*	*2.67*
Total red meat emissions	***133.36***	***70.86***	***57.50***	***52.28***	***63.96***	***54.61***
Total national emissions	605.09	524.14	509.36	505.97	517.57	507.98
Proportion total national emissions (%)	22.0	13.5	11.3	10.3	12.4	10.7

Table 3. Greenhouse gas emissions (Mt CO_2-e) from farm, feedlot, and processing sectors

Source of emissions	**2005**	**2015**	**2016**	**2017**	**2018**	**2019**
Farm	129.55	67.12	54.11	48.84	60.29	50.76
Feedlot	2.37	2.37	2.22	2.28	2.45	2.61
Processing	1.45	1.37	1.16	1.16	1.22	1.24

Table 4. Contribution of beef cattle, sheep meat, and goats to greenhouse gas emissions (Mt CO_2-e) from the Australian red meat sector.

Source of emissions	**2005**	**2015**	**2016**	**2017**	**2018**	**2019**
Cattle	116.26	63.11	53.37	50.17	58.22	48.58
Sheep meat	17.04	7.68	4.06	2.04	5.68	5.96
Goats	0.07	0.08	0.07	0.07	0.07	0.07

Figure 1. Change in area of sparse woody vegetation between 1990 and 2019. Data is from the Australian National Greenhouse Gas Inventory activity tables. Area is total national area of vegetation gains and losses.

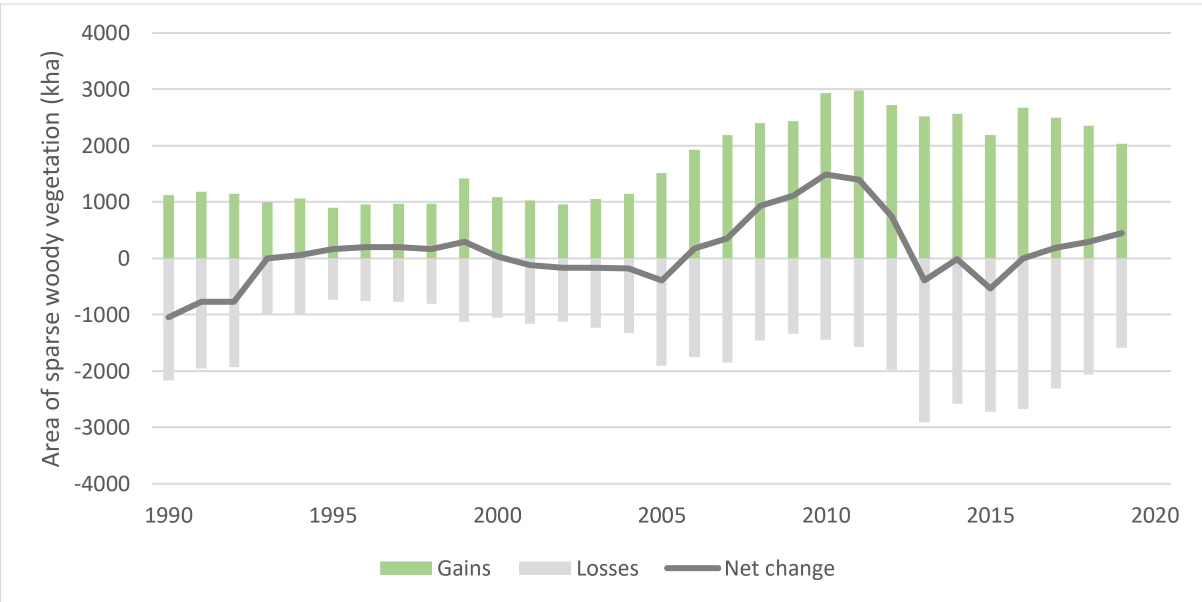

Figure 2. Change in area of forest between 1990 and 2019. Land clearing is from a combination of primary conversion and reclearing. Data is from the Australian National Greenhouse Gas inventory activity tables. Area is total national area of vegetation gains and losses.

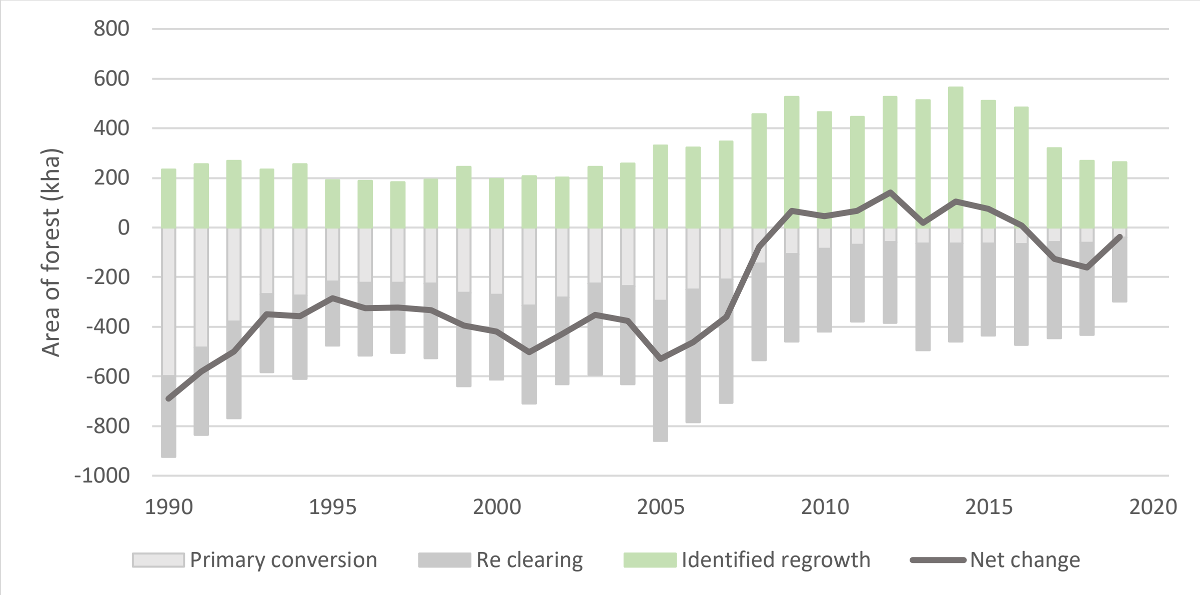

Table 5. Livestock numbers and red meat production in 2005, 2015-2018. Data is from the Australian National Greenhouse Gas Inventory activity tables and ABS annual statistics.

	2005	2015	2016	2017	2018	2019
Beef						
Total beef cattle[1] (million head)	25.2	24.6	24.3	24.9	25.1	23.7
Beef cattle pasture (million head)	24.4	23.7	23.3	24.0	24.1	22.6
Beef cattle feedlot (million annual equivalents[2])	0.82	0.93	0.94	0.94	1.03	1.11
Beef produced[3] (million tonnes)	2.06	2.51	2.10	2.13	2.29	2.40
Sheep						
Total sheep (million head)	100.7	70.9	70.9	75.7	74.1	69.0
Lamb & mutton produced (million tonnes)	0.62	0.71	0.69	0.70	0.74	0.73
Wool produced (greasy)	0.46	0.36	0.36	0.38	0.36	0.31

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

4.2 Emissions factors

The UNFCCC National GHG Inventory current reports emissions using GWP_{100} CO_2-e from the IPCC AR4. From 2020-21, the inventory will start using GWP_{100} values from the AR5. The higher global warming potential of CH_4 in the AR5 report would cause a small increase in the amount of emissions attributed to red meat production (Table 6). 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.

Table 6. GHG emissions in 2005 and 2017 calculated using different CO_2-e metrics

Emissions metric	Assessment report	Total national emissions (Mt CO_2e)		Emissions from red meat (Mt CO_2e)		% national emissions from red meat	
		2005	2019	2005	2019	2005	2019
GWP_{100}	AR4	605.1	508.0	133.4	54.6	22.0	10.7
GWP_{100}	AR5	617.6	519.0	138.9	59.5	22.5	11.5
GWP_{20}	AR4	843.6	718.0	235.5	146.2	27.9	20.4
GWP_{20}	AR5	902.6	770.0	260.9	169.0	28.9	21.9
GTP_{100}	AR5	492.9	409.1	85.7	11.8	17.4	2.9
GTP_{20}	AR5	817.2	694.7	224.3	136.1	27.4	19.6

4.3 Changes since 2018 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 listed below. The impact on emissions attributed to red meat production has been small.

- Review of emissions factor used to estimate N_2O emissions from dryland feedlots. This has led to a reduction in emissions from manure management, and a small increase in emissions from animal waste applied to soil.
- A revision of land areas leading to a recalculation of total grassland area, and more accurate information on where different plant species grow in northern pasture lands. This led to a small increase in emissions.
- Changes to timing of events in FullCAM modelling to provide more accurate estimates of plant cover and organic carbon decays in cropland and grasslands. This led to a small decrease in emissions.
- Improvements to spatial fire simulations in South East Australia to provide more accurate estimates of emissions from prescribed burning, leading to decrease in emissions in *Forest land remaining forest land*
- Updated spatial datasets for forest cover change, leading to a small increase in emissions associated with forests in *land converted to forest land*
- An adjustment to the ratio of decomposable to resistant plant material in unimproved grasslands species, and a reduction in the N leaching fraction in croplands and grasslands, leading to a reduction in emissions

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:

- Periodic review of feed and animal characteristics
- Review methods, parameters, and activity data to estimate enteric methane from beef cattle and sheep
- Research to provide a more accurate estimation of N_2O emissions from feedlot manure based on key drivers such as temperature, rainfall and manure moisture
- Review and update of factor to estimate fraction of N lost through runoff and leaching

- On-going improvements in remote sensing programmes to provide more accurate estimates of land use and land use changes
- Review of land use data sets to improve reporting of land use change
- Improved modelling of methane emissions from reservoirs and other constructed water ponds such as farm dams, in conjunction with improved spatial analysis of small water bodies at a national scale

5. Conclusion

5.1 Key findings

This report shows that emissions from the red meat industry have remained relatively stable in 2016-2019. 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.

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

While some emissions from the red meat industry are able to be reported directly from the National GHG inventory, emissions from areas such as vegetation management and energy are estimated based on data describing red meat production systems. Suggestions to improve the accuracy of these estimates are listed below. These could be included in future reports but require time to develop.

1. Review of method to estimate emissions from goat production, focusing on attribution of emissions from grazing lands.
2. Explore the potential for including emissions related to fertilizer production, supplementary feed used on farm, and transportation processes.
3. Review of methods to estimate emissions from processing. Current estimates are based on Ridoutt et al. (2015), who reported energy use of beef processing in 2003, 2008 and 2013. This data does not capture differences in energy use between sheep and beef processing plants, or improvements in efficiency since 2013.
4. Collaboration with DISER to provide more accurate estimation of emissions from LULUCF based on mapping of sheep, cattle, and goat production systems.

7. References

ABARES 2017. Australia's forests at a glance 2017: with data to 2015–16. Canberra: Australian Bureau of Agricultural and Resource Economics and Sciences.

ABARES 2021. Agricultural commodity statistics 2021. Canberra: Australian Bureau of Agricultural and Resource Economics and Sciences.

ABS 2014. 4360.0 Agricultural Resource Management Practices Australia 2011-12. Canberra: Australian Bureau of Statistics.

ABS 2019. 4610.0 Water Account, Australia, 2016-17. Canberra: Australian Bureau of Statistics.

ABS 2021. 7215.0 - Livestock Products, Australia. Canberra: Australian Bureau of Statistics.

ALL ENERGY PTY LTD 2021. 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. Sydney: Australian Meat Processor Corporation and Meat & Livestock Australia.

CLEAN ENERGY REGULATOR 2021. Global warming potentials http://www.cleanenergyregulator.gov.au/NGER/About-the-National-Greenhouse-and-Energy-Reporting-scheme/global-warming-potentials [accessed April 2022]

DISER 2021a. National Inventory Report 2019 Volume 1. Canberra: Australian Government Department of Industry, Science, Energy and Resources.

DISER 2021b. National Inventory Report 1029 Volume 2. Canberra: Australian Government Department of Industry, Science, Energy and Resources.

DISER 2021c. Activity Table 1990-2019 - Agriculture – LivestockNational Canberra: Australian Government Department of Science, Industry, Energy and Resources. https://ageis.climatechange.gov.au/QueryAppendixTable.aspx

DOEE 2017. National Greenhouse and Energy Reporting Scheme Measurement Technical Guidelines for the estimation of emissions by facilities in Australia. Canberra: Department of the Environment and Energy.

IPCC 2007. Climate change 2007 – The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. New York: Intergovernmental Panel on Climate Change.

LYNCH, J. 2019. Availability of disaggregated greenhouse gas emissions from beef cattle production: A systematic review. *Environmental Impact Assessment Review*, 76, 69-78.

MAYBERRY, D., BARTLETT, H., MOSS, J., DAVISON, T. & HERRERO, M. 2019. Pathways to carbon-neutrality for the Australian red meat sector. *Agricultural Systems,* 175**,** 13-21.

MYHRE, G., SHINDELL, D., BRÉON, F.-M., COLLINS, W., FUGLESTVEDT, J., HUANG, J., KOCH, D., LAMARQUE, J.-F., LEE, D., MENDOZA, B., NAKAJIMA, T., ROBOCK, A., STEPHENS, G., TAKEMURA, T. & ZHAN, H. 2013. Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *In:* STOCKER, T. F., QIN, D., PLATTNER, G.-K., TIGNOR,

M., ALLEN, S. K., BOSCHUNG, J., NAUELS, A., XIA, Y., BEX, V. & MIDGLE, P. M. (eds.). Cambridge, United Kingdom and New York, NY, USA.

RIDOUTT, B., SANGUANSRI, P. & ALEXANDER, D. 2015. Environmental Performance Review: Red Meat Processing Sector 2015 FINAL REPORT. North Sydney: Australian Meat Processor Corporation.

WIEDEMANN, S., DAVIS, R., MCGAHAN, E., MURPHY, C. & REDDING, M. 2017. Resource use and greenhouse gas emissions from grain-finishing beef cattle in seven Australian feedlots: a life cycle assessment. *Animal Production Science*, 57, 1149-1162.

WIEDEMANN, S. G., LEDGARD, S. F., HENRY, B. K., YAN, M.-J., MAO, N. & RUSSELL, S. J. 2015. Application of life cycle assessment to sheep production systems: investigating co-production of wool and meat using case studies from major global producers. *The International Journal of Life Cycle Assessment*, 20, 463-476.

WIEDEMANN, S. G., YAN, M.-J. & MURPHY, C. M. 2016. Resource use and environmental impacts from Australian export lamb production: a life cycle assessment. *Animal Production Science*, 56, 1070-1080.

8. Appendix

8.1 List of commonly used terms and acronyms

CO_2-e	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 change 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	Megatonne. Equivalent to 1 million metric tonnes.
Tier 1-3	The IPCC uses 'tiers' to rate the complexity of methods used to estimate GHG emissions. Tier 2 and 3 use more complex methods and higher resolution data, and are considered more accurate than Tier 1, which uses a simple first order approach.
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 Previous red meat inventory reports

Project number	Project name	Inventory year
B.CCH.7714	Greenhouse Gas mitigation potential of the Australian red meat production and processing sectors	2015
E.CEM.1909	Greenhouse gas footprint of the Australian red meat and processing sectors	2016
E.CEM.1932	Greenhouse gas footprint of the Australian red meat production and processing sectors 2017 and 2018 updates	2017, 2018
B.CCH.1016 (this report)	Greenhouse Gas Footprint of the Australian Red Meat Production and Processing Sectors 2019	2019

8.3 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 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 (ABARES 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 2021c). 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) _ENREF_3, 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 2021). 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 allocation to meat 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 2021). Greasy wool yield is reported by ABARES (2021).

The volume of liveweight and wool produced each year varies due to seasonal conditions. In 2019, 64% 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 2021a; DISER 2021c). This was divided by the total cropland area (DISER 2021b) 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 2019, we estimated that 4.4% 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 2021). 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.