Final report

Red meat greenhouse gas emissions update 2021

Project code: B.CCH.2124

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Date published: 2 May 2024

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

Abstract

This report provides updated estimates of emissions attributable to the Australian red meat industry based on the 2021 Australian National Greenhouse Gas Inventory. The report presents greenhouse gas emissions for beef cattle, sheep meat and goats in 2021, and recalculates emissions from 2005–2020 using current inventory data.

In 2021, net greenhouse gas emissions from the red meat industry were 31 Mt CO_2-equivalents representing a 40% decrease compared with 2020, and a 78% decrease compared with the reference year of 2005 when total emissions were 145 Mt CO_2-equivalents.

These changes in emissions are primarily due to a reduction in clearing of forest and sparse woody vegetation, and an increase in vegetation growth and carbon storage.

Reductions in livestock emissions (enteric methane, manure management) since 2005 are also related to changes in the national herd size. Similar to previous reports, the majority of emissions in 2021 are associated with enteric methane produced by grazing beef cattle, and land cleared and converted to grassland.

Executive summary

Background

Understanding the sources of, and changes in, greenhouse gas emissions from red meat production is important to help the red meat industry achieve its sustainability goals. In a previous project (B.CCH.7714), a method was developed to quantify greenhouse gas emissions from red meat production based on the Australian National Greenhouse Gas Inventory. This current project provides an updated estimate of emissions from red meat production in Australia in 2021, and in comparison with a 2005 baseline.

Objectives

- Calculate greenhouse gas emissions from the Australian red meat industry using data from the 2021 Australian National Inventory (GWP100, AR5 values). Emissions were reported by:
    - sources of emissions
    - contribution to total national emissions
    - commodity; beef cattle, sheep meat, goats
    - sector; farm, feedlot, processing sectors.
- Calculate total greenhouse gas emissions from the Australian red meat industry using GWP20, GTP100, GTP20, direct methane, GWP* and radiative forcing.
- Report livestock numbers and red meat production volumes.

Methodology

Emissions from the Australia's National Greenhouse Accounts 2021 Paris Agreement Inventory were allocated to beef cattle (on pasture and in feedlots), sheep meat, and goats based on animal numbers, resource use and processing volumes.

Results/key findings

Emissions from the Australian red meat industry in 2021 were 31 Mt CO_2-equivalents. Most emissions are associated with enteric methane produced by grazing beef cattle, and carbon stock change in forest land converted to grassland. Large volumes of carbon stored in above and below ground biomass, particularly in forest lands, reduce the overall net position.

Net emissions from the red meat industry have decreased by 78% since 2005. These changes are largely due to a reduction in the clearing and reclearing of forest and sparse woody vegetation, and an increase in vegetation growth and carbon storage. Emissions from livestock (e.g., enteric methane, manure management) have also decreased since 2005 in response to changes in animal numbers, particularly the national sheep flock, which has decreased from 100.7 to 71.4 million heads.

Benefits to industry

Annual reporting of emissions enables performance tracking with respect to industry targets. The emissions profile can inform research and development as well as other strategic actions.

Future research and recommendations

The report provides recommendations of data that would improve the accuracy of these calculations, and capture improvements in efficiency made on-farm and in feedlots.

Acknowledgements

Brad Ridoutt (CSIRO) is acknowledged for his contribution in calculating radiative forcing emissions.

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1. Background

The Australian red meat industry is a source of greenhouse gas emissions that contribute to climate change. As part of its sustainability goals, the industry has a target to achieve net zero greenhouse gas emissions by 2030 and has been benchmarking its greenhouse gas emissions footprint annually since 2015.

This report provides an update of greenhouse gas emissions (carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)) from the Australian red meat sector based on the 2020-21 Paris Agreement Inventory (hereafter referred to as the *National Inventory*) published by Australia's National Greenhouse Accounts (Australian Government 2023a).

2. Objectives

1. Calculate the 100-year Global Warming Potential (GWP100) greenhouse gas footprint of the Australian red meat production for 2021 including:
    a. sources of emissions
    b. contribution to national emissions
    c. emissions by commodity; cattle, sheep meat and goats
    d. emissions by sector; farm, feedlot, and processing.
2. Calculate the GWP20, Global Temperature Potential (GTP)100, GTP20, as per previous years' reporting.
3. Calculate total red meat sector emissions using direct methane (i.e., tonnes CH_4), GWP* and radiative forcing.
4. Report livestock numbers and red meat production volumes.

3. Methodology

3.1 Scope of reporting

This report provides an estimate of greenhouse gas emissions attributable to the red meat industry in the baseline year of 2005, and annually from 2015 to 2021. The scope of this assessment includes the production of beef cattle, sheep meat, and goats, as well as the domestic processing of these animals.

Emissions from the following sources are included:

- enteric fermentation
- manure management
- agricultural soils, both direct and indirect soil emissions from grasslands and the fraction of croplands used to support the production of feedlot rations
- field burning of agricultural (crop) residues
- liming and urea applications
- electricity and fuel use on farms, in feedlots, and in processing
- land use and land use change relating to cropland, grassland and forest available for grazing
- farm dams and ponded pastures.

Emissions from dairy cattle[1], buffalo and wool production were not included.

Due to data and methodological limitations, this analysis was also unable to include emissions associated with domestic transport of livestock, live export animals after they leave Australia, wild-harvested animals (e.g., feral goats), 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 and other farming inputs.

3.2 Data sources and allocation of emissions to the red meat industry

Emissions were allocated to the Australian red meat industry using the method of Mayberry *et al.* (2018). Calculations are based primarily on emissions reported by the Australian Government National Greenhouse Accounts, supplemented by other data on livestock populations and processing (Table 1). Each year the Australian Government Department of Climate Change, Energy, the Environment and Water review and update activity data and the inventory methodology, and changes are applied retrospectively to previous years. Thus, this report supersedes previous project reports describing the distribution of greenhouse gas emissions from the red meat sector using this method.

Table 1: Key datasets used in this analysis

Data	Source	Location of dataset
Greenhouse gas emissions from agriculture and land use	Australia's National Greenhouse Accounts; Paris Agreement Inventory	https://greenhouseaccounts.climatechange.gov.au
Livestock populations data	Australia's National Greenhouse Accounts; Activity tables (based on data from the Australian Bureau of Statistics and Australian Lot Feeders Association)	https://greenhouseaccounts.climatechange.gov.au
Meat and wool production	ABS Livestock Products	https://www.abs.gov.au/statistics/industry/agriculture/livestock-products-australia

The Department of Climate Change, Energy, the Environment and Water publishes national emissions inventories on an annual basis to meet Australia's reporting requirements under the Paris Agreement, United Nations Framework Convention on Climate Change (UNFCCC), and Kyoto Protocol (Table 2). The biggest difference between the Paris Agreement, UNFCCC, and Kyoto Protocol inventories is the GWP values used to calculate CO_2-equivalents (CO_2-e), and the details of sectors which emissions are reported against. This report uses data from the Paris Agreement Inventory, which uses GWP100 values from the Fifth Assessment Report (AR5) and reports against UNFCCC sectors.

2020-21 is the first year that the Department have published the Paris Agreement Inventory, with previous reports prepared for MLA using data from the UNFCCC Inventory.

[1] milking cows, cull dairy cows, replacement heifers, bobby calves/vealers and dairy bulls

Table 2: Summary of emissions inventories published as part of Australia's National Greenhouse Accounts. Data from the Paris Agreement Inventory, highlighted in grey shading, is used to estimate the emissions from the red meat industry published in this report.

Inventory name	Details	Sectors	GWP values
Paris Agreement Inventory	National inventory used to track progress towards Paris Agreement targets	Total UNFCCC	AR5
State and territory emissions	National inventory disaggregated by Australian state and territory	Subsectors of total UNFCCC	AR5
National inventory by economic sector	National inventory disaggregated using Australian and New Zealand Standard Industrial Classification (ANZSIC)	Total of all economic (ANZSIC) sectors	AR5
Scope 2 emissions by economic sector	Estimates of indirect emissions from purchased electricity generation	Total of all economic (ANZSIC) sectors	AR5
Paris Agreement inventory memo items	Additional emissions sources, including international aviation and shipping	Memo items	AR5
UNFCCC Inventory	National inventory used to report emissions under the UNFCCC	Total UNFCCC	AR4
Kyoto Protocol inventory	National inventory used to track progress against Australia's 2020 targets	National Greenhouse Gas Inventory Total	AR4

Under the Paris Agreement, emissions are reported for energy, industrial processes, agriculture, land use land use change and forestry (LULUCF), and waste. Most emissions from the red meat industry are from the agriculture and LULUCF sectors, with small contributions from the energy sector. Emissions reported by the National Inventory are allocated to the red meat industry based on animal numbers, feed intake, meat production and resource use as described by Mayberry *et al.* (2018). A broad summary of how emissions are allocated to the red meat industry is provided below, with details related to specific emissions categories in Table 3. Note that emissions from farm dams and ponded pastures have not previously been included in reporting of emissions to MLA and are new to this report. For more details on the methods and data used by the Department of Climate Change, Energy, the Environment and Water to calculate emissions, readers are referred to the National Inventory Reports (Australian Government 2023a; 2023b).

Allocation of emissions between livestock species

The National Inventory reports emissions associated with livestock activities (enteric methane, manure management and degradation of urine and faeces in the field) for each species, and separates cattle into dairy cattle, beef cattle on pasture, and beef cattle in feedlots. All emissions from beef cattle on pasture, beef cattle in feedlots and goats were reported directly from the inventory.

The national sheep flock produces both meat and wool, and emissions were attributed to either commodity using the protein mass allocation method (Wiedemann *et al.* 2015). This method calculates the amount of protein in animal liveweight and wool based on the volume of mutton and lamb produced (Australian Bureau of Statistics 2023a), gross weight of live export sheep (Australian Bureau of Statistics 2019), and greasy wool yields (Australian Bureau of Statistics 2022). In 2021, 58.27% of protein produced by sheep was in meat and 41.73% in wool. The proportion of protein in meat (i.e., 0.58 in 2021) was applied to total sheep emissions to calculate emissions from sheep. Because the amount of meat and wool produced varies between years, this calculation was repeated for each year of data.

The National Inventory calculates emissions from livestock based on livestock population data from the Australian Bureau of Statistics. Recent research (Fordyce *et al.* 2021; Wiedemann *et al.* 2024) has shown that livestock population data published by the Australian Bureau of Statistics may under report the actual number of livestock in Australia. The National Inventory may therefore also be under reporting livestock emissions. While this uncertainty is acknowledged, it is important that the results published in this report are consistent with data by the Australian National Greenhouse Gas Accounts to enable direct comparison with total national emissions and (if required) other industries.

Attribution of cropland emissions to red meat

Cropland is used to produce grain fed to cattle in feedlots, with emissions associated with soil tillage, application of fertilisers, degradation of organic matter, fire, and land clearing. 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 used to produce grain for feedlot cattle was calculated based on the number of cattle in feedlots, days on feed and average daily liveweight gain (Australian Government 2023b). This was divided by the total cropland area (Australian Government 2023a; Table 6.2.2) to provide the proportion of cropland that contributes to feedlot cattle production. This proportion was then applied to all cropland emissions in the inventory to estimate cropland emissions attributable to red meat production.

Proportion of grazing lands used for beef and sheep-meat production

Emissions from grazed pasture (including pasture and forages sown on cropland), grasslands and forests include emissions from application of inorganic fertiliser and degradation of organic matter, fire, and land clearing. Grasslands and forest lands can also be a carbon sink, with carbon stored in above and below ground biomass. These emissions are reported by the National Inventory under the Agriculture and LULUCF sectors at a national level and are allocated to the red meat industry as described below.

In the Agriculture sector, direct and indirect emissions from soils are reported separately for irrigated and non-irrigated pastures. The proportion of emissions from irrigated pasture allocated to red meat is calculated based on the proportion of irrigated pasture land used by beef cattle and sheep. The Australian Bureau of Statistics previously reported 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 2017). The average proportion of irrigated pasture land used for *production from meat cattle* (0.30) was applied to the National Inventory emissions from irrigated pastures to calculate beef cattle emissions from irrigated pastures. The same process was used to calculate emissions from sheep grazing irrigated pastures, except that the area of irrigated pasture used for *sheep and other livestock* (0.20) is not able to be further disaggregated, and the entire area is allocated to sheep, then corrected for co-production of meat and wool as described above. While this likely overestimates the area of irrigated pasture used for sheep production, the total emissions from irrigated pastures are small, so this has minimal impact on the emissions included in the red meat inventory.

Direct and indirect emissions from non-irrigated pastures reported under the Agriculture sector are allocated to the red meat industry on the basis of resource use. Time-series spreadsheets provided by the Department of Climate Change, Energy, the Environment and Water estimate total annual feed intake for dairy cattle, beef cattle, 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, silage, or grain), forms much of the diet of grazing beef cattle and sheep. The proportion of grazing land used for sheep production is corrected for co-production of meat and wool as outlined above.

For the LULUCF sector, emissions from *grassland remaining grassland*, *land converted to grassland*, *forest land remaining forest land* and *land converted to forest land* are also allocated to the red meat industry based on the relative feed intake of different livestock types as described above. It is assumed that all grasslands are used for grazing, but only a portion of forest lands are grazed. Emissions from *forest land remaining forest land* are reported for *harvested native forests, plantations,* and *other native forests* in the National Inventory Report (Table 6.4.1; Australian Government 2023a). Emissions from harvested native forests and plantations are excluded on the basis that these are unlikely to be used for grazing. The area of *other native forest* available for grazing (and therefore proportion of emissions associated with grazing industries) is estimated based on the area of leasehold and private forest reported in Australia's State of the Forests Report (ABARES 2023), i.e., excluding the area of forest used for nature conservation and as multiple-use public forests. It is noted that there is significant uncertainty associated with these assumptions, nor is this approach able to account for regional differences in emissions and carbon storage associated with different forest types. This has been identified as an area for improvement in future reports.

Energy use on farm, in-feedlots and in processing

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 (Australian Government 2023b). 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) and numbers of animals. 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 described above.

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 (Australian Government 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; Ridoutt and Sikes 2023), and volume of meat produced (Australian Bureau of Statistics 2023a). The method accounts for improvements in processing efficiency captured in the Red Meat Processing Sector Environmental Performance Reviews conducted every 5 years.

Table 3: Overview of methods used in the Paris Agreement Inventory (Australian Government 2023a), and the basis of allocation of these emissions to the red meat industry

Emissions source	Emissions relevant to red meat production	National inventory method	Allocation of emissions to the red meat industry
Agriculture			
Enteric methane	Methane produced as a by-product of digestion by ruminants	Emissions from cattle and sheep are based on estimated dry matter intake of livestock in each season (summer, autumn, winter, spring). Emissions from goats are calculated as using average emissions of 5kg CH_4/head/year.	All emissions from beef cattle feedlot, beef cattle pasture and goats were reported directly from the national inventory. Emissions from sheep were corrected for the co-production of meat and wool. Emissions from all other livestock were excluded.
Manure management	Methane from decomposition of organic matter under anaerobic conditions; N_2O from deposition of N volatilized from manure management systems	Based on estimated manure production and N excreted in faeces and urine	All emissions from beef cattle feedlot, beef cattle pasture and goats were reported directly from the national inventory. Emissions from sheep were corrected for the co-production of meat and wool. Emissions from all other were livestock excluded.
Agricultural soils	Direct and indirect emissions of N_2O from soils following application of fertilisers, urine and dung deposited by grazing animals, decomposition of crop and pasture residues, mineralisation due to loss of soil carbon, and cultivation of histols	Based on volume of inorganic or organic fertiliser applied to soil, and volume of faeces and urine excreted by grazing animals	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 the co-production of meat and wool. Emissions from all other livestock were excluded. Direct and indirect emissions from cropland were included based on the proportion of cropland required to supply grain to feedlots. Direct and indirect emissions from irrigated pasture were calculated based on the proportion of irrigated pasture used for beef and sheep meat production. The area of irrigated pasture used for sheep production was corrected for the co-production of meat and wool. The area of non-irrigated pasture was attributed to beef or sheep meat based on relative feed intake.
Field burning of agricultural residues	Methane and N_2O emissions from stubble burning	Based on annual crop production, amount of crop residue remaining after	Emissions were included based on the proportion of cropland required to supply feedlots.

		harvest/grazing, fraction of annual crop that is burnt, and burning efficiency	
Liming	CO_2 emissions from reaction of carbonates with acids in soil	Volume of lime and dolomite applied to soils multiplied by default IPCC emissions factors	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 (Australian Bureau of Statistics 2014). Volume of lime used for sheep farming was corrected for the co-production of meat and wool.
Urea application	Loss of CO_2 fixed in urea during the manufacturing process	Volume of urea applied to soils multiplied by IPCC default emissions factor	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 (Australian Bureau of Statistics 2014). Volume of urea fertiliser used for sheep farming was corrected for the co-production of meat and wool.
Land use, land use change and forestry			
Forest land	Emissions from burning, land clearing and soils; Carbon storage in growth of woody vegetation.	Carbon stock changes and emissions are modelled using the Full Carbon Accounting Model (FullCAM) using spatial data on land use, land clearing, forest planting, natural regeneration and the area and timing of prescribed burns and wildfires. The modelling accounts for spatial and temporal variations in climate, soil, and vegetation.	Emissions from *forest land remaining forest land* were calculated based on area of forest land available for grazing (i.e., excluding plantations, harvested forests, areas protected for biodiversity and conservation (ABARES 2023)), with this allocated between beef cattle and sheep based on relative feed intake. Emissions from sheep were corrected for the co-production of meat and wool. It is assumed that dairy cattle do not graze on forest lands. Emissions from *grassland converted to forest land* are allocated to the red meat industry based on relative feed intake by beef cattle, dairy cattle and sheep within each state or territory. Emissions from sheep were corrected for the co-production of meat and wool. Emissions from *cropland converted to forest land* are allocated to the red meat industry based on the proportion of cropland required to supply feedlots.
Cropland	Emissions from changes in management practices from changes in crop type and land use		Emissions were included based on the proportion of cropland required to supply feedlots.

Grassland	Emissions from changes in management practices (pasture, grazing, fire management), changes in sparse woody vegetation, and land clearing		Emissions were allocated to the red meat sector based on relative feed intake of beef cattle, dairy cattle, and sheep in each state or territory. Emissions from sheep were corrected for the co-production of meat and wool.
Wetland	Methane emissions from farm dams and ponded pastures		All emissions from *other constructed water bodies*, which includes stock dams, crop dams, farm tanks and ponded pastures were included. Emissions were allocated to beef cattle and sheep based on feed intake. Emissions from sheep were corrected for the co-production of meat and wool.

3.3 Changes since the last report and anticipated changes to future reporting

No changes have been made in this report to the methodology used to allocate emissions from the National Inventory to the red meat sector, except for the additional inclusion of emissions from farm dams and ponded pastures. This change contributed to the small increase to total emissions attributable to the red meat industry, but also makes this assessment more thorough and complete.

In line with their international reporting requirements, the Department of Climate Change, Energy, the Environment and Water reviews and updates the methods and data used to calculate national emissions every year. These revisions improve the accuracy of reported emissions and are applied retrospectively to previous inventories. Changes to the National Inventory that are of relevance to the red meat industry reporting are summarised in Table 4, with planned improvements that may be implemented in future inventory releases (Australian Government 2023a) also highlighted.

While not specifically referenced in the 2021 National Inventory Report (Australian Government 2023a), the Australian Bureau of Statistics is currently modernising the way they produce statistics, including their estimates of livestock populations (Australian Bureau of Statistics 2023b). It is expected that updated livestock population estimates will be available for the 2022-23 financial year. When this data is published, it can then be included in the National Inventory. It is likely that total livestock emissions (e.g., enteric methane, manure) will increase in response to the revised population data. However, because the Department of Climate Change, Energy, the Environment and Water apply updated data to all reporting years, the reduction in livestock emissions between 2005 and 2021 will still be reflected in the National Inventory accounts.

Table 4: Changes to national inventory calculations in 2020-21, and planned improvements (Australian Government 2023a)

Source	Changes this year	Planned improvements
Enteric methane	None	• Periodic review of feed and animal characteristics • Review methods, parameters and activity data for feedlot cattle • Review methods and parameters for sheep
Manure management	None	• Revise method to calculate N_2O emissions from manure mass
Agricultural soils	• Updates to crop information in 2018–19 & 2019–20 • Revisions to soil carbon losses for N mineralisation	• Improved source data on emissions factors for inorganic fertilisers • Consider disaggregation of emissions factors for urea and non-urea fertilisers • Investigate use of emissions factors specific to climate zones
Field burning ag residues	None	None
Liming	None	• Identify current data on limestone and dolomite application to ag soils
Urea application	None	• Investigate use of country specific emissions factors
Forest land	• Revision to forest productivity index spatial data • Refinements to FullCAM • Activity data updates	• Tier 3 method for *harvested native forests* • Improved calibrations for forest growth and disturbance • Improved methods to measure forest cover change
Cropland	• Activity data updates • Updated crop yields • Revision to forest productivity index spatial data • Refinements to FullCAM • Activity data updates	• Refined spatial allocation of crop species and yields • Improved modelling of below ground debris pool • Improved estimated of tillage impacts • Review of stubble management practices • Improved calibrations for forest growth and disturbance • Improved methods to measure forest cover change
Grassland	• Revision to forest productivity index spatial data • Refinements to FullCAM • Activity data updates	• Improvements to FullCAM model • Improved resolution of forest change data • Improved calibrations for forest growth and disturbance
Wetlands (farm dams & ponded pasture)	• Activity data updates • Continued improvements to reservoir model • New model to estimate emissions from farm dams	• Improvements to reservoir model

3.4 Analysis of emissions

In this report, emissions from the red meat sector are reported as Mt of CO_2, CH_4, N_2O and CO_2-e. The warming potential of emissions (radiative forcing) is reported as milli watts per square meter (mW/m^2). The CO_2-e metric allows comparison between different gases by indicating the amount of energy each gas absorbs relative to CO_2 (Lynch 2019).

There are several different CO_2-e metrics that can be expressed over different timescales; usually 20 or 100 years (Table 5). The primary metric to report emissions from the red meat sector is GWP100 and unless otherwise indicated, values in this reported are calculated using the GWP100 values from the AR5 report. Emissions for the total red meat industry have also been calculated under alternate metrics.

Table 5: Global warming and global temperature potentials used in presentation of emissions results. Values are exclusive of climate-carbon feedbacks. (Myhre et al. 2013). Values used in the 2021 Paris Agreement Inventory and this report are highlighted in grey.

	GWP100 AR5	GWP100 AR4	GWP20 AR5	GTP100 AR5	GTP20 AR5
CO_2	1	1	1	1	1
CH_4	28	25	84	4	67
N_2O	265	298	264	234	277

The IPCC Sixth Assessment Report (AR6; (Forster *et al.* 2021)) includes updated GWP100 values, including the differentiation between CH_4 from fossil and non-fossil origins. However, these values are not yet used in Australia's National Inventory reporting, and not considered in this analysis.

Global warming potential; GWP100 and GWP20

GWP is the most widespread CO_2-e and is a measure of how much energy a greenhouse gas traps in the atmosphere over a given time period relative to CO_2. It is calculated by multiplying the volume of each gas by the GWP metric (Table 4).

GWP*

The GWP* climate metric assesses the future warming potential associated with a permanent change in the rate of emission of short-lived greenhouse gases such as CH_4. To quantify the change in rate, emissions need to be assessed over a time interval. The developers of GWP* use a 20-year time interval, arguing that this smooths out short-term fluctuations in emission rates that may not reflect permanent change (Allen *et al.* 2018). The GWP* result for methane was calculated following Smith *et al.* (2021) and using the AR5 GWP100 values in Table 4.

$$Emissions = 1.13\ (r\ H\ \Delta E(t)) / \Delta t + 1.13\ s\ E(t)$$

Where:

r = represents the response to changing emission flow or <u>*rates*</u>; 0.75

s = represents the long-term equilibration of emission <u>*stocks*</u>; 0.25

H = time horizon used for GWP calculations; 100 years

ΔE(t) = change in emissions over 20 years, calculated using GWP100

Δt = time period of interest; 20 years

E(t) = emissions in current year, calculated using GWP100

Long-lived greenhouse gases, namely CO_2 and N_2O, were assessed using the conventional GWP100 metric values of 1 and 265 (Myhre *et al.* 2013). Results were reported as CO_2-equivalent emissions by combining the amounts of all three gases.

Global Temperature change Potential; GTP100 and GTP20

The 100-year and 20-year GTP (GTP100 and GTP20, respectively) reports the modelled change in global mean surface temperature at a point in time 100 or 20 years after a pulse emission. GTP is calculated as for GWP, using the AR5 values in Table 4.

Radiative forcing climate footprint

The radiative forcing footprint combines radiative forcing from current year emissions and the radiative forcing from historical emissions remaining in the atmosphere (Ridoutt 2021; ISO 2021). Due to their long lifetime, historical emissions of CO_2 and N_2O are highly important as they accumulate over time. Methane emissions have a much shorter atmospheric lifetime and the radiative forcing curve from a pulse emission decays comparatively quickly. The profile of radiative forcing over time informs about whether progress is being made toward radiative forcing stabilisation, which is a requirement for climate stabilization. In this study, the radiative forcing associated with a pulse emission was calculated using parameters and equations reported in (Myhre *et al.* 2013).

4. Results

4.1 Greenhouse gas emissions from the red meat industry

Emissions reported using GWP100 values

Total net greenhouse gas emissions attributable to the Australian red meat industry in 2021 were 31.1 Mt CO_2-e (Table 6). The main sources of emissions were enteric methane (41.8 Mt CO_2-e) and grasslands (17.5 Mt CO_2-e), with large volumes of sequestration in forest land (-41.0 Mt CO_2-e) reducing the overall net position.

Enteric methane emissions are mostly from grazing beef cattle (31.9 Mt CO_2-e), with smaller contributions from sheep meat (7.8 Mt CO_2-e), beef cattle in feedlots (2.0 Mt CO_2-e) and goats (0.1 Mt CO_2-e) (Appendix 7.2).

Emissions from grazing lands include land converted to grasslands (17.6 Mt CO_2-e), grasslands remaining grasslands (-0.2 Mt CO_2-e), forest lands remaining forest lands (-6.7 Mt CO_2-e) and land converted to forest lands (-34.2 Mt CO_2-e). Emissions from land conversion are associated with changes in carbon stocks, i.e., carbon lost or stored as above and below ground biomass through management, fire, or growth. Across all LULUCF categories, there are small emissions from soils, N mineralisation, leaching and runoff, and carbon stored in woody vegetation.

Table 6: Greenhouse gas emissions from the Australian red meat sector. Values are Mt CO_2 equivalents calculated using GWP100 values from the AR5 report.

Source	**2005**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Agriculture	*55.97*	*53.14*	*52.38*	*54.14*	*54.50*	*52.31*	*49.63*	*51.33*
Enteric fermentation	46.70	43.72	42.98	44.49	44.86	42.71	40.39	41.82
Manure management	3.96	4.02	3.89	4.01	4.05	3.91	3.69	3.78
Agricultural soils	4.91	4.93	5.01	5.10	5.07	5.17	5.03	5.15
Field burning of agricultural residues	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02
Liming and urea	0.39	0.47	0.48	0.53	0.51	0.50	0.52	0.55
Land use, land use change and forestry	*86.12*	*25.31*	*4.42*	*-0.34*	*7.06*	*-3.63*	*-0.58*	*-22.68*
Cropland	0.35	0.06	-0.10	-0.11	-0.09	-0.11	0.10	0.18
Grassland	93.11	41.33	34.24	31.55	37.32	21.41	29.54	17.45
Forest land	-7.90	-16.69	-30.34	-32.50	-30.85	-25.58	-30.80	-40.95
Wetland	0.55	0.61	0.62	0.72	0.68	0.65	0.58	0.64
Energy	*2.90*	*2.71*	*2.49*	*2.54*	*2.62*	*2.59*	*2.37*	*2.43*
Farm and feedlot	1.47	1.37	1.35	1.39	1.41	1.36	1.28	1.30
Processing	1.42	1.34	1.15	1.15	1.21	1.23	1.09	1.13
Total red meat emissions	***144.98***	***81.17***	***59.29***	***56.34***	***64.18***	***51.27***	***51.42***	***31.08***
Total national emissions	616.29	540.91	512.48	509.81	514.23	505.86	494.23	464.77
Proportion total national emissions (%)	23.52	15.01	11.57	11.05	12.48	10.14	10.40	6.69

Since 2005, net emissions attributable to the red meat industry have decreased by 114 Mt CO_2-e or 78% (Table 6). This reduction in emissions is primarily due to a substantial decrease in emissions from the LULUCF sector associated with a reduction in the clearing and reclearing of forest land and sparse woody vegetation (see appendix 7.2). Emissions from land converted to grassland have decreased by 60 Mt from 78 Mt CO_2-e to 18 Mt CO_2-e. There has also been an increase in carbon stocks in land converted to forest land, with net emissions decreasing by 21 Mt CO_2-e from -13 Mt CO_2-e to -34 Mt CO_2-e. Emissions from grassland remaining grassland have decreased by 17 Mt CO_2-e.

Between 2020 and 2021 there was a large decrease in emissions from grasslands and an increase in carbon stored in forest lands (Table 6), driven by combination of reduced land clearing and increased growth of both forests and sparse woody vegetation (Appendix 7.2). These changes mean that total emissions from the red meat industry in 2021 are 20 Mt CO_2-e or 40% less than in 2020. However, it is important to note the high level of inter-annual variability in LULUCF emissions since 2015, with no consistent trends in net emissions from this sector (Table 6). This is because emissions from LULUCF are influenced by a combination of natural and anthropogenic factors (e.g., land management, rainfall, fire) which vary both spatially and temporally across Australian grazing landscapes. Thus, the large reduction in emissions between 2020 and 2021 may not be sustained in subsequent years.

Changes in emissions from the agriculture sector to date have been driven by livestock numbers (Table 7) due to the contribution of enteric CH_4. Overall, there has been a decrease in emissions from agriculture since 2005 and 2021 (Table 6), largely in response to a reduction in sheep numbers. There was a small increase in cattle and sheep numbers, and therefore also enteric CH_4 emissions, between 2020 and 2021. Despite the association between livestock numbers and agricultural emissions it is difficult to link changes in emissions to the volume of red meat produced (i.e., an emissions intensity metric) because these statistics do not account for the number of live animals exported from Australia. Processing volumes may also be influenced by seasonal and market conditions. Reducing direct emissions from enteric methane, manure and energy usage by the red meat industry continue to be essential to achieve lasting net emissions reduction from the agricultural sector.

On a species basis, the majority (88%) of emissions from the red meat industry are from beef cattle production (Table 8 and Appendix 7.2), reflecting the large volume of enteric methane produced (34 Mt CO_2-e) and area of land used for grazing. This is supported by the dominance of on-farm emissions, compared to those from feedlots and processing (Table 9 and Appendix 7.2). Emissions from beef cattle and sheep meat production have decreased since 2005, with this decrease driven by changes in land management. There has been little change in emissions from goats because the method used in this report cannot account for LULUCF emissions from goat meat production.

Table 7: Livestock numbers and red meat production. Population data is from the National Inventory activity tables (Australian Government 2024a) and livestock products are from the Australian Bureau of Statistics (2022, 2023a). Volume of goat meat produced is not reported by either agency.

	2005	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Beef								
Total beef cattle (million head)	25.2	24.6	24.2	24.9	25.1	23.7	22.3	23.3
Beef cattle pasture (million head)	24.4	23.7	23.3	24.0	24.1	22.6	21.2	22.3
Beef cattle feedlot (million annual equivalents[1])	0.82	0.93	0.94	0.94	1.03	1.11	1.11	1.06
Beef produced[2] (million tonnes)	2.13	2.62	2.32	2.05	2.22	2.33	2.35	1.92
Sheep								
Total sheep (million head)	100.7	70.9	70.9	75.7	74.1	69.0	66.7	71.4
Lamb & mutton produced (million tonnes)	0.62	0.71	0.69	0.70	0.74	0.73	0.66	0.66
Wool produced (greasy)	0.46	0.36	0.36	0.38	0.36	0.31	0.28	0.34
Goats								
Total goats (million head)	0.46	0.52	0.46	0.46	0.46	0.46	0.46	0.46

[1] Number of animals adjusted for days on feed

[2] Excluding veal

Table 8: Greenhouse gas emissions from the Australian red meat sector by species. Values are Mt CO_2 equivalents calculated using GWP100 values from the AR5 report.

	2005	2015	2016	2017	2018	2019	2020	2021
Beef	125.09	70.89	54.07	53.37	58.14	45.48	45.73	27.27
Sheep meat	19.82	10.19	5.15	2.89	5.97	5.71	5.61	3.73
Goats	0.08	0.09	0.08	0.08	0.08	0.08	0.08	0.08

Table 9: Greenhouse gas emissions from the Australian red meat sector by location. Values are Mt CO_2 equivalents calculated using GWP100 values from the AR5 report.

	2005	2015	2016	2017	2018	2019	2020	2021
Farm	141.03	77.28	55.74	52.74	60.38	47.28	47.34	26.89
Feedlot	2.53	2.55	2.41	2.45	2.59	2.75	3.00	3.06
Processing	1.42	1.34	1.15	1.15	1.21	1.23	1.09	1.13

Table 10: Greenhouse gas emissions from the red meat industry expressed using different climate metrics. Values for GWP and GTP are expressed as Mt CO_2 equivalents and calculated using AR5 values from Table 4. Radiative forcing is expressed as mW/m^2. GWP values for 2005 were unable to be calculated.*

	2005	2015	2016	2017	2018	2019	2020	2021
GWP 100	144.98	81.17	59.29	56.34	64.18	51.27	51.42	31.08
GWP 20	270.93	200.96	175.42	175.96	182.05	163.80	156.93	137.99
GTP 100	90.01	28.84	8.55	4.09	12.73	2.10	5.28	-15.65
GTP 20	233.09	165.00	140.56	140.04	146.65	130.02	125.28	105.90
GWP*		49.28	17.32	19.04	21.57	-1.21	-31.33	-47.87
Radiative forcing	5.72	7.11	7.10	7.11	7.12	7.10	7.06	6.99

Emissions reported using alternative metrics

The Paris Agreement Inventory reports emissions using GWP100 values from the AR5 report, and it is recommended that MLA also use these values in reporting emissions from the red meat industry (Table 6) until the National Inventory adopts the AR6 report GWP100 values. National emissions from the red meat industry are also reported for 2005 and 2015-2021 using GWP20, GTP100 and GTP20 values and radiative forcing (Table 10). GWP* values are not available for 2005 as 20 years of data is required for the calculation and are reported here from 2015 onwards.

Regardless of which metrics are used, the decrease in emissions attributable to the red meat industry are largely associated with changes in land management, i.e., reduced land clearing and increased vegetation growth.

The negative net GWP* values in 2019, 2020 and 2021 (Table 10) reflect that total CH_4 emissions from the red meat industry were lower in those years compared with 1999, 2000 and 2001, respectively. While CH_4 emissions have declined over this period, CH_4 emissions associated with the red meat industry are still occurring (Table 11), and are contributing to global warming.

Table 11: Methane emissions (Mt) from the red meat industry in 2020 and 2021. CO_2 equivalents are calculated using GWP100 values from the AR5 report. Emissions in 2020 are provided as the baseline for comparison in the Global Methane Pledge.

	CH_4		**CO_2-e**	
	2020	2021	2020	2021
Agriculture	1.56	1.62	43.78	45.32
Land use, land use change & forestry	0.32	0.29	8.99	8.15
Energy	0.00	0.00	0.00	0.00
Total methane emissions from red meat	***1.88***	***1.91***	***52.77***	***53.47***
Total national methane emissions	*4.42*	*4.37*	*123.77*	*122.36*
% total national methane emissions	*42.5*	*43.7*		

As a short-lived but powerful climate pollutant, continued reductions in CH_4 are important to reduce global warming. Methane emissions from the red meat industry account for 44% of total national CH_4 emissions (Table 11). Most CH_4 emissions from the red meat industry are from enteric CH_4, and there has been a slight increase in total CH_4 emissions from the red meat industry between 2020 and 2021 in response to increasing numbers of both cattle and sheep. In comparison, total national CH_4 emissions decreased between 2020 and 2021.

Reductions in CH_4 emissions will require activities that reduce enteric CH_4 production. However, the industry still lacks on- or near-to-market options for direct enteric CH_4 reduction, particularly those suitable for extensive grazing industries where most CH_4 emissions originate (e.g., northern Australian beef systems).

5. Conclusion

5.1 Key findings

- Greenhouse gas emissions attributable to the Australian red meat industry in 2021 were 31 Mt CO_2e.
- Emissions attributable to the red meat industry have decreased by 40% since 2020 and 78% since 2005.
- Emissions from the industry are balanced by carbon storage in the landscape.
- The conversion of forest lands to grasslands continues to generate emissions, even though the area of land clearing has been substantially reduced.
- Storage of carbon in grazing landscapes is sensitive to climatic conditions, and continued progress towards net zero goals will require a reduction in animal emissions, particularly enteric CH_4.

5.2 Benefits to industry

Annual reporting of greenhouse gas emissions from red meat production enables 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

The following limitations of the method used to attribute emissions from the National Inventory to the red meat industry have been identified. These limitations are consistent with those provided in the Common Approach to Sector-Level Greenhouse Gas Accounting for Australian Agriculture report (Sevenster *et al.* 2023). Research and funding to address these limitations would increase the accuracy of the red meat industry greenhouse gas footprint.

- Significant emissions and carbon storage are associated with the LULUCF sector, but the estimates generated in this report are associated with high levels of uncertainty. This uncertainty stems from a combination of the activity data and modelling approach used in the National Inventory, and the methods used in this report to allocate emissions from LULUCF to the red meat industry. Collaboration with the Department of Climate, Energy, the Environment and Water could enable LULUCF emissions to be generated at finer spatial scales and mapped against areas used for beef cattle, sheep, and goat production. This would also allow emissions from *Croplands* to be disaggregated into crops and pastures sown in rotation.
- Emissions attributable to the red meat industry in this report are incomplete due to data and methodological limitations. There is potential to further develop this methodology to include emissions related to fertiliser production, supplementary feed used on-farm, and transportation processes.
- Emissions from energy and the area of cropland used to support cattle in feedlots are based on historic life cycle assessments (Wiedemann *et al.* 2017; Wiedemann *et al.* 2016; Wiedemann *et al.* 2015). The efficiency of these systems is likely to have changed since the

assessments were completed. More current data would enable these improvements to be captured in reporting of emissions.

- Data on where and how goats are managed is scarce. Better data on goat populations, including feral animals that are harvested for meat or export, would enable more complete reporting of emissions associated with the goat industry.

7. Appendix

7.1 Common acronyms used in this report

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
AR5	IPCC Fifth Assessment Report
CH_4	Methane
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
GTP	Global Temperature Potential
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use, land use change and forestry
N_2O	Nitrous oxide
UNFCCC	United Nations Framework Convention on Climate Change

7.2 Supporting evidence and additional results

Table 12: Greenhouse gas emissions from the Australian red meat sector by species in 2021. Values are CO2 equivalents calculated using GWP100 values from the AR5 report.

Source	Beef cattle	Sheep meat	Goats
Agriculture	*41.80*	*9.45*	*0.08*
Enteric fermentation	33.98	7.78	0.06
Manure management	3.38	0.40	0.00
Agricultural soils	4.03	1.12	0.01
Field burning of agricultural residues	0.02	-	-
Liming and urea	0.40	0.16	-
Land use, land use change and forestry	*-16.28*	*-6.40*	-
Cropland	0.18	-	-
Grassland	14.33	3.12	-
Forest land	-31.31	-9.64	-
Wetland	0.52	0.12	-
Energy	*1.75*	*0.69*	-
Farm and feedlot	0.91	0.39	-
Processing	0.84	0.30	-
Total emissions per species	***27.27***	***3.73***	***0.08***
Proportion of red meat emissions (%)	87.74	12.02	0.25

Table 13: Greenhouse gas emissions from the Australian red meat sector by location in 2021. Values are CO2 equivalents calculated using GWP100 values from the AR5 report.

Source	Farm	Feedlot	Processing
Agriculture	*48.51*	*2.81*	-
Enteric fermentation	39.81	2.02	-
Manure management	3.37	0.41	-
Agricultural soils	4.84	0.31	-
Field burning of agricultural residues	-	0.02	-
Liming and urea	0.49	0.06	-
Land use, land use change and forestry	*-22.84*	*0.16*	-
Cropland	-	0.18	-
Grassland	17.45	-	-
Forest land	-40.93	-0.02	-
Wetland	0.64	-	-
Energy	*1.22*	*0.08*	*1.13*
Farm / feedlot	1.22	0.08	-
Processing	-	-	1.13
Total emissions per species	***26.89***	***3.06***	***1.13***
Proportion of red meat emissions (%)	86.51	9.84	3.65

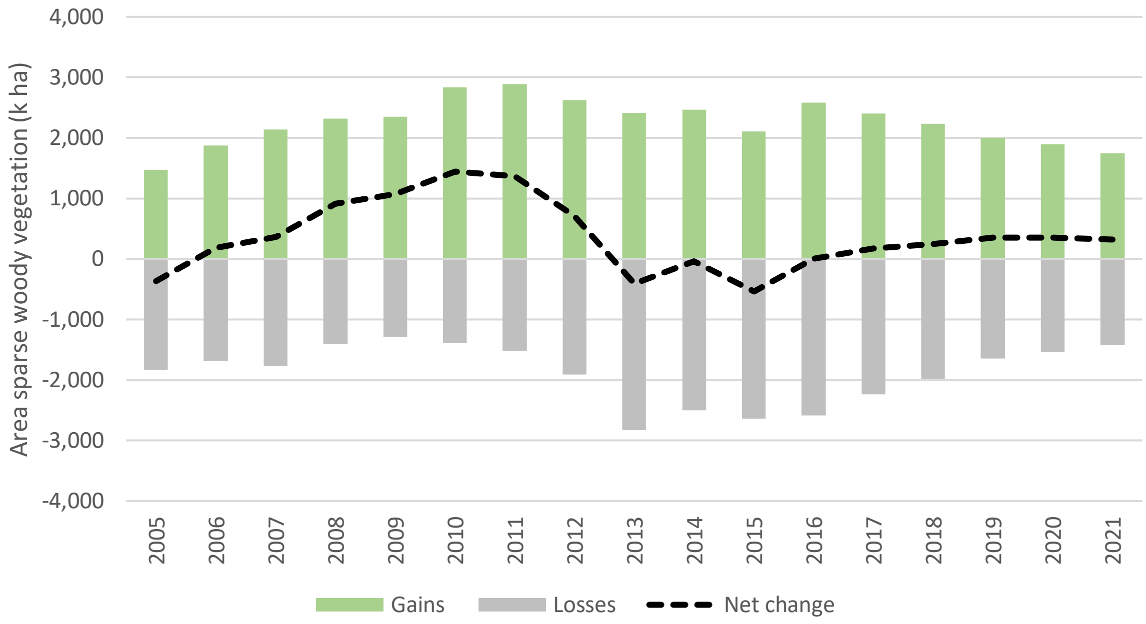

Figure 1: Change in area of sparse woody vegetation since 2005. Values are total national area of clearing and regrowth of sparse woody vegetation, and include areas not used for red meat production. Data is from the national inventory activity tables (Australian Government 2024b).

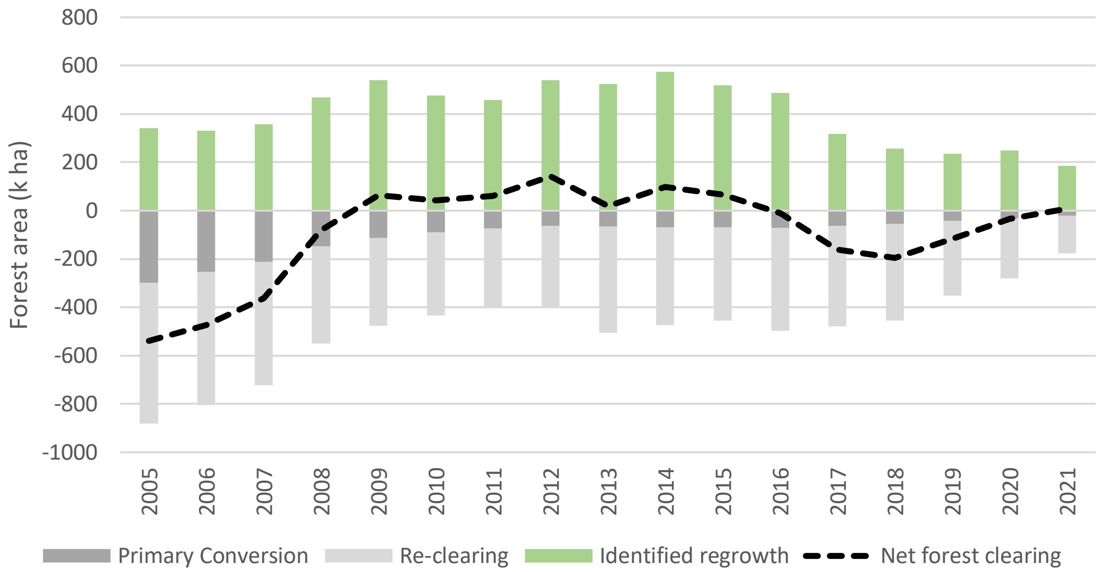

Figure 2: Change in area of forest land since 2005. Values are total national area of forest clearing and regrowth, and include areas not used for red meat production. Data is from the national inventory activity tables (Australian Government 2024b).

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