Final report

Assessment of climate accounting metrics for the Australian red meat industry

Project code: B.CCH.2117

Prepared by: Brad Ridoutt and Di Mayberry
CSIRO Agriculture and Food

Date published: 16 August 2021

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

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

Abstract

The Australian red meat industry is a source of greenhouse gas (GHG) emissions, including carbon dioxide, nitrous oxide, and methane. These emissions differ in lifetime and greenhouse effect. The combined climate impact can be expressed using a climate metric and most reporting, target-setting and abatement strategy currently uses GWP100. This project investigates the potential of other scientifically valid options that may be more relevant, especially in relation to methane, a relatively short-lived GHG. An inventory of emissions was compiled from 1990 to 2018 that was extrapolated to 2030. Emissions profiles were assessed using GWP100, GTP100, GTP2100, GWP*, CGTP75 and the radiative forcing (RF) footprint. As expected, the results obtained were highly impacted by the choice of climate metric. Regarding the potential adoption of a “climate neutral” target aligned with the climate stabilization goal of the Paris Agreement, three metrics (GWP*, CGTP75 and RF footprint) have the potential to be used and their strengths and weaknesses are described. The adoption of a climate neutral target could have important implications for GHG mitigation strategy, as there is no requirement for methane emissions to be reduced to zero or otherwise offset. Technologies that reduce methane emissions can create scope for the industry to grow sustainably.

Executive summary

Background

The Australian red meat industry is a source of greenhouse gas (GHG) emissions, including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Each type of GHG emission has a different impact on the climate over time as there are differences in atmospheric lifetime, as well as strength of greenhouse effect.

Climate metrics can be used to establish an equivalence between different types of GHG emissions. Typically, results are reported as CO_2-equivalent emissions. However, there is no absolute equivalence in climate impact. Depending on the climate metric chosen, the relative importance of the different GHGs varies.

Most GHG reporting, target-setting and abatement strategy is based on results obtained using the GWP100 climate metric. This project investigates the potential of other scientifically valid options that may be more relevant, especially in relation to methane, a relatively short-lived GHG.

This report is intended to inform GHG emissions reporting and abatement strategy in the Australian red meat industry and to inform the potential adoption of a “climate neutral” target. The intended audience is the stakeholders engaged in these decisions.

Objectives

This project had three objectives:

1. Develop a timeseries of GHG emissions for the Australian red meat industry disaggregated by sector (sheep, cattle), GHG (CO_2, CH_4, N_2O), covering the period 1990 to present (with extrapolation to 2030), and including land use and land use change
2. Report the industry’s emissions profile using a range of climate accounting approaches: GWP, GTP, GWP*, radiative forcing climate footprint
3. Identify potential implications of alternative climate metrics with respect to the adoption of a climate neutral target for the industry and mitigation strategies, and make recommendation for future action

All these objectives were met. In relation to Objective 2, the range of climate metrics used was expanded to include new metrics that were considered relevant.

Methodology

Disaggregated timeseries of GHG emissions (CO_2, N_2O and CH_4) for the production of beef cattle and sheep meat were compiled for the years 1990 to 2018 using data predominantly obtained from the National Greenhouse Gas Inventory using methods previously adopted by MLA. These emission timeseries were projected forward to 2030 using a simple linear model.

The timeseries of emissions were assessed using a variety of climate metrics: GWP100, GTP100, GTP2100, GWP*, CGTP75 and the radiative forcing (RF) footprint.

Results/key findings

The application of different climate metrics led to very different emissions profiles for the Australian red meat industry over time.

However, it is important to acknowledge that there is no universally correct way of aggregating a basket of different GHG emissions and reporting the combined climate impact. The impacts differ over time and different climate metrics each offer a perspective.

When emissions of different GHGs are aggregated, the priority should be to select an approach that is relevant to the strategic goal. Regarding the potential adoption of a "climate neutral" target for the industry, it is important to recognize that this term is currently not officially defined. One way of applying the term is in relation to the goal of climate stabilization. Article 2 of the Paris Agreement describes the goal of limiting the increase in global mean temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C. This can be broadly described as climate stabilisation as the goal is not to allow global mean temperatures to keep increasing indefinitely, and nor is it to pursue efforts to return the climate to a pre-industrial condition. Importantly, to stabilise the climate a target of net zero emissions is relevant in the case of long-lived GHGs, such as carbon dioxide and nitrous oxide. However, a more-or-less stable emissions trajectory of a short-lived GHG like methane is compatible with climate stabilization.

For the adoption of a climate neutral target that is aligned with the goal of climate stabilization, there are three relevant GHG assessment and reporting options: GWP*, CGTP75 and RF footprint.

Benefits to industry

The adoption of a climate neutral target could have important implications for GHG mitigation strategy, as there is no requirement for methane emissions to be reduced to zero or otherwise offset. There could be a need to give greater emphasis to strategies for the mitigation of long-lived GHG emissions (CO_2 and N_2O). The report also highlights the potential dangers of strategies that seek to mitigate methane emissions but lead to higher CO_2 and N_2O emissions.

Positively, there is evidence that the sheep meat industry is already climate neutral, and the beef cattle industry is not far away from this goal.

Under the kind of climate neutral strategy described in this report, technologies that reduce methane emissions can create scope for the industry to grow sustainably.

Future research and recommendations

The report makes six recommendations that relate to:

1. Reviewing the inventory method for production system emissions
2. Pursuing efforts to reduce the uncertainty associated with Land Use, Land Use Change and Forestry (LULUCF) emissions estimates
3. Documenting individual LULUCF emissions
4. Developing a process-based systems model to quantify future emissions
5. Consulting with stakeholders about the formal adoption of a climate neutral strategy
6. Exploring pathways for the formal definition and quantification of "climate neutrality"

Table of contents

1. Background

The Australian red meat industry is a source of greenhouse gas (GHG) emissions, such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), that contribute to climate change. These GHGs vary in radiative efficiency (i.e.: strength of greenhouse effect) and atmospheric lifetime. As such, it is a challenge to assess and report climate impacts in a multi-gas approach as the impacts associated with each type of GHG vary over time. Climate metrics are used to establish *equivalence* between different GHG emissions. Typically, results are reported as CO_2-equivalent emissions. However, there is no absolute equivalence in climate impact. Depending on the climate metric chosen, the relative importance of the different GHGs varies.

Currently, most reporting, target-setting, and abatement strategy for GHG emissions is based on results obtained using the 100-year Global Warming Potential (GWP100) climate metric. However, this climate metric has limitations and is not always suitable for use in all situations and policy contexts. One specific limitation of the GWP100 climate metric is that it obscures the very different climate impacts over time of short-lived GHGs (like methane) and long-lived GHGs (like carbon dioxide).

GWP100 was adopted pragmatically as part of the political process used to establish the Kyoto Protocol in the 1990s. As mentioned above, climate metrics can be helpful in facilitating multi-gas agreements and policies. However, the United Nation's Intergovernmental Panel on Climate Change (IPCC) has noted that the GWP climate metric, "should not be considered as having any special significance", that there is, "no scientific argument for selecting 100 years compared to other choices", and that the decision to apply the GWP100 climate metric is a, "value judgement" (Myhre et al., 2013). Furthermore, a recent IPCC expert meeting on short-lived climate forcers (which includes methane), recommended that these emissions should not be converted to CO_2-equivalent emissions using GWP100 (IPCC, 2018).

The relevance of the GWP100 climate metric can also be questioned in relation to the 2015 Paris Agreement (UNTC, 2015). Two key clauses are cited below:

Article 2

Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change

Article 4

…so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century,

While there is some scope for differences in interpretation of the global average temperature target, the goal can broadly be described as climate stabilisation. A major problem with the GWP100 climate metric is that it is difficult to interpret results in relation to this goal as the metric integrates radiative forcing contribution over a future 100-year time horizon (Ridoutt and Huang, 2019).

It is also important to note that the Paris Agreement does not use the terms "net zero" or "carbon neutral". To stabilize the climate within any near or medium term, clearly long-lived GHG emissions must achieve net zero. However, for short-lived GHG emissions, which come and go on relatively short time scales, a more-or-less stable emissions profile can be consistent with climate stabilization.

Consequently, for industries with substantial short-lived emissions, such as the Australian red meat industry, it is relevant to consider the use of climate metrics other than GWP100 and the applicability of GHG emissions reduction targets other than net zero or carbon neutrality.

The adoption of alternative climate metrics and climate goals could potentially have major implications for climate action and communication with stakeholders.

2. Objectives

This project had three objectives:

1. Develop a timeseries of GHG emissions for the Australian red meat industry disaggregated by sector (sheep, cattle), GHG (CO_2, CH_4, N_2O), covering the period 1990 to present (with extrapolation to 2030), and including land use and land use change.
2. Report the industry's emissions profile using a range of climate accounting approaches: GWP, GTP, GWP*, radiative forcing climate footprint.
3. Identify potential implications of alternative climate metrics with respect to the adoption of a climate neutral target for the industry and mitigation strategies, and make recommendation for future action

All these objectives were met. In relation to Objective 2, the rage of climate metrics used was expanded to include new metrics that were considered relevant.

3. Methodology

3.1 Timeseries of emissions 1990 to 2018

Disaggregated timeseries of GHG emissions (CO_2, N_2O and CH_4) for the production of beef cattle and sheep meat were compiled for the years 1990 to 2018 using data predominantly obtained from the National Greenhouse Gas Inventory (DISER 2020b, 2020c), using methods described by Mayberry et al. (2018) and outlined in Appendix 8.1. The system boundary included the following emission sources:

- enteric methane and manure
- production of livestock feed (pastures for grazing livestock, grain used in feedlot rations)
- land management (e.g.: clearing, management and regrowth of native vegetation)
- electricity and fuel used on farms and in feedlots

Attribution of cropland emissions to red meat was based on the number of beef cattle in feedlots along with estimates of the cropland requirements to support feedlot cattle reported by Wiedemann et al. (2017).

Emissions related to irrigated pasture were attributed to beef cattle and sheep production using data reported by ABS (2019). Emissions related to non-irrigated pasture were attributed to beef cattle and sheep using estimates of feed intake derived from the National Greenhouse Gas Inventory.

Although some dairy cattle are processed for meat, these animals were considered by-products of the dairy industry, and emissions from dairy cattle were excluded.

Emissions from sheep production were attributed to either meat or wool using the protein mass allocation method (Wiedemann et al., 2015), and emissions from wool were also excluded.

To be consistent with previous annual inventory reports undertaken for MLA, the analysis excluded emissions associated with domestic transport of livestock, live export animals after they leave Australia, cropland used to produce grain fed to livestock outside beef cattle feedlots (e.g.: confinement fed sheep), the manufacture and transport of roughages (e.g.: hay and silage), and the manufacture and transport of fertilisers.

3.2 Extrapolation of timeseries to 2030

Using the inventory developed in Subsection 3.1, annual production system emissions of CO_2, N_2O and CH_4 were extrapolated to 2030 after a least squares linear trend line was fitted to the time series data. In the case of land use and land use change emissions, trends in the time series data were less apparent. As such, CO_2, N_2O and CH_4 emissions related to land use and land use change were projected to 2030 based on the average of the past 5 years. These extrapolations were undertaken separately for beef cattle and sheep meat. The purpose of these projections was to provide an indication of potential progress toward the CN30 goal of carbon neutrality with business as usual. This does not represent a prediction of future emissions based on a complex systems model.

3.3 Analysis of emissions

The timeseries of emissions developed in Subsections 3.1 and 3.2 were assessed using a variety of climate metrics as described below:

3.3.1 100-year Global Warming Potential (GWP100)

The 100-year Global Warming Potential (GWP100) reports the integral of radiative forcing (area under the curve) over a future 100-year time horizon following a pulse emission. The metric values for CO_2, CH_4 and N_2O of 1, 28 and 265 were obtained from Myhre et al. (2013), with results reported as CO_2-equivalent emissions.

3.3.2 100-year Global Temperature change Potential (GTP100)

The 100-year Global Temperature change Potential (GTP100) reports the modelled change in global mean surface temperature at a point in time 100 years after a pulse emission. The metric values for CO_2, CH_4 and N_2O of 1, 4 and 234 were obtained from Myhre et al. (2013), with results reported as CO_2-equivalent emissions.

3.3.3 Global Temperature change Potential in year 2100 (GTP2100)

This climate metric is like GTP100 described above; however, the temperature change potential is modelled for the fixed future year of 2100. This metric was included because it was recently recommended in a confidential draft document produced by FAO. In this case, the metric values change each year as the time interval to the year 2100 decreases. In the year 2000, the metric values are identical to GTP100 (as there is 100 years between the years 2000 and 2100). In the year 2030, the metric values are the same as GTP70. The metric values were calculated using parameters and equations reported in Myhre et al. (2013). Similarly, results were reported as CO_2-equivalent emissions.

3.3.4 Global Warming Potential (star) (GWP*)

The GWP* climate metric assesses the future warming potential associated with a permanent change in the rate of emission of a short-lived GHG. To quantify the change in rate, emissions need to be assessed over a time interval. The developers of GWP* demonstrate use of 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). In this study, a time interval of 15 years was used. This was to enable the reporting of results beginning in the year 2005 (i.e.: 15 years after the beginning of the emissions time series – 1990). The GWP* result for methane was calculated following Smith et al. (2021) and using the GWP100 value of 28 for methane reported by Myhre et al. (2013). Long-lived GHGs, namely CO_2 and N_2O, were assessed using the conventional GWP100 metric values of 1 and 265 (Myhre et al., 2013) as described in Subsection 3.3.1. Results were reported as CO_2-equivalent emissions. In summary, this climate metric is like GWP100 except that pulses of long-lived GHGs are evaluated along with permanent rates of change of short-lived GHGs emissions.

3.3.5 75-year Combined Global Temperature change Potential (CGTP75)

Like GWP*, the 75-year Combined Global Temperature change Potential (CGTP75) evaluates pulses of long-lived GHGs in combination with permanent rates of change of short-lived GHG emissions. However, it differs in time horizon (75 years), its impact parameter (temperature change potential) as well as other details in the way metric values were quantified. This metric was included in the study as it is presented by the authors as a methodological improvement over the GWP* (Collins et al., 2020). Application of the metric followed Collins et al. (2020), using a 15-year interval to ascertain rate of change in methane emissions. Results were reported as CO_2-equivalent emissions.

3.3.6 Radiative forcing climate footprint (RF footprint)

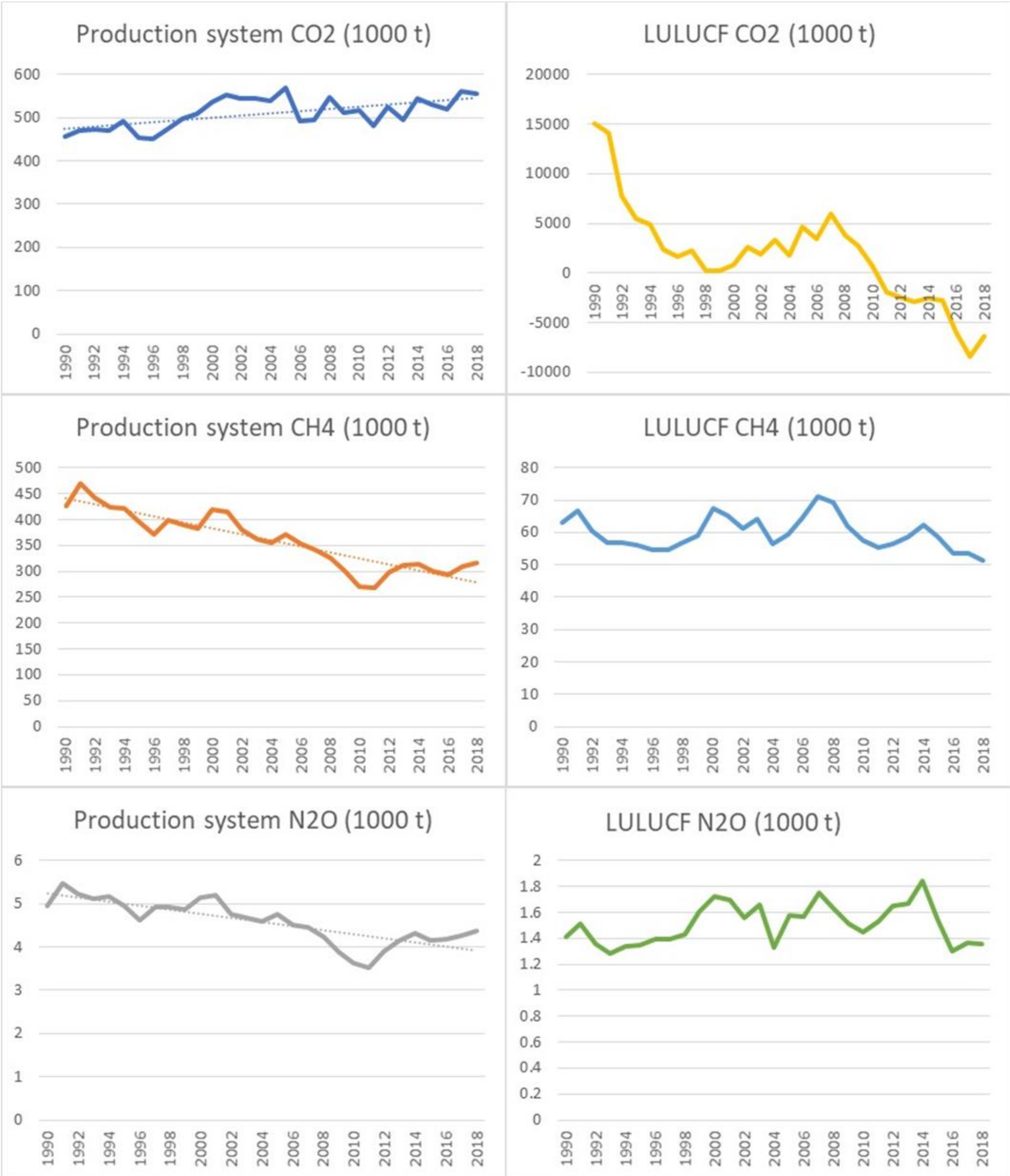
The RF footprint combines radiative forcing from current year emissions and the radiative forcing from historical emissions remaining in the atmosphere (Ridoutt, 2021; ISO, 2021). Due to their long lifetime, historical emissions of CO_2 and N_2O are highly important as they accumulate over time. Methane 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 stabilization, which is a requirement for climate stabilization. In this study, the RF associated with a pulse emission was calculated using parameters and equations reported in Myhre et al. (2013). The results were reported in the units milli watts per square meter (mW/m2).

4. Results

4.1 Disaggregated GHG emission profiles

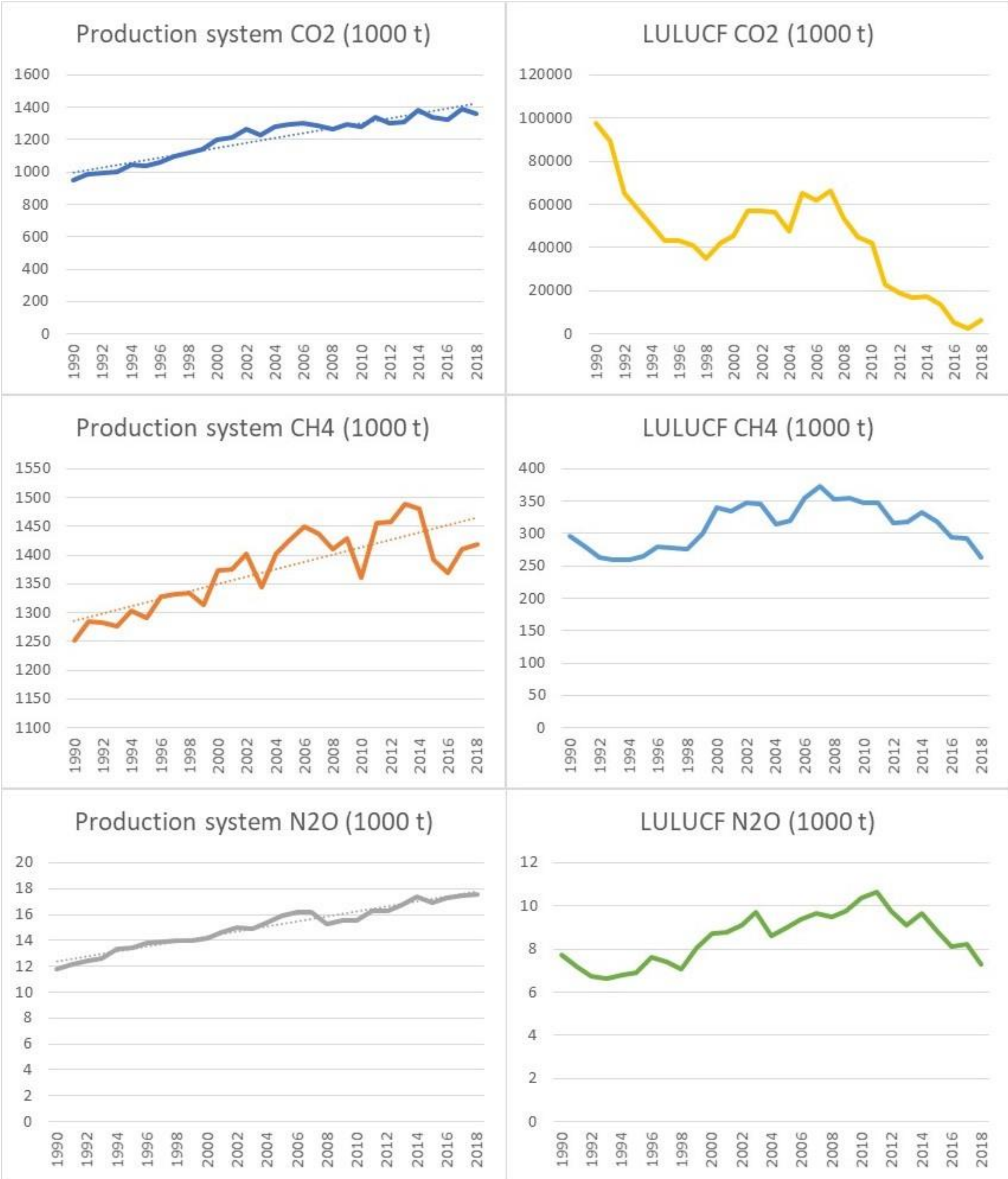
The disaggregated GHG emissions profile for the sheep meat industry is shown in Figure 1. Over the period 1990 to 2018, production system emissions of CO2 were rising, whereas production system emissions of CH4 and N2O were in decline. Emissions of CO2 related to land use change and land management trended steeply downward from 1990 to 1998, but subsequently increased over the period 1998 to 2007, before trending downward again, achieving negative values from 2011 onwards. However, in 2018 there was less CO2 sequestration than in 2017. Emissions of CH_4 and N_2O related to land use change and land management were up and down and demonstrated no obvious trend over time.

Figure 1. Disaggregated GHG emissions profiles for the sheep meat industry



The disaggregated GHG emissions profile for the beef cattle industry is shown in Figure 2. Over the period 1990 to 2018, production system emissions of CO_2, CH_4 and N_2O were all rising. As was the case for the sheep meat industry, emissions of CO_2 related to land use change and land management initially trended steeply downward, but subsequently increased before again trending downward. Unlike the sheep meat industry, CO_2 emissions from land use change and land management in the beef cattle industry have yet to fall below net zero. Emissions of CH_4 and N_2O related to land use change and land management were up and down and demonstrated no obvious trend over time.

Figure 2. Disaggregated GHG emissions profiles for the beef cattle industry



4.2 Aggregated emissions profiles

4.2.1 100-year Global Warming Potential (GWP100)

The aggregated emissions profiles for the sheep meat and beef cattle industries assessed using the GWP100 climate metric are presented in Figure 3. For the sheep meat industry, total emissions have been trending downward, from 18.9 Mt CO_2-e in the baseline year of 2005 to 6.0 Mt CO_2-e in 2018, which is a 68% reduction. Emissions are projected to fall to 4.2 Mt CO_2-e in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2. In 2018, the largest GHG emission source was enteric methane (8.42 Mt CO_2-e, Table 1). The largest sink was grassland converted to forestland (-6.81 Mt CO_2-e). For the beef cattle industry, total emissions have also declined, from 122.1 Mt CO_2-e in the baseline year of 2005 to 61.2 Mt CO_2-e in 2018, which is a 50% reduction. Emissions are projected to rise marginally to 69.4 Mt CO_2-e in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2.

For the beef cattle industry, it is important to note that although total emissions have fallen, production system emissions have steadily increased. In 2018, the largest GHG emission source was enteric methane (34.45 Mt CO_2e, Table 1), closely followed by land converted to grassland (31.11 Mt CO_2e). The largest sink was grassland converted to forestland (-19.24 Mt CO_2-e).

Figure 3. Aggregated emissions profiles for the sheep meat and beef cattle industries assessed using the GWP100 climate metric

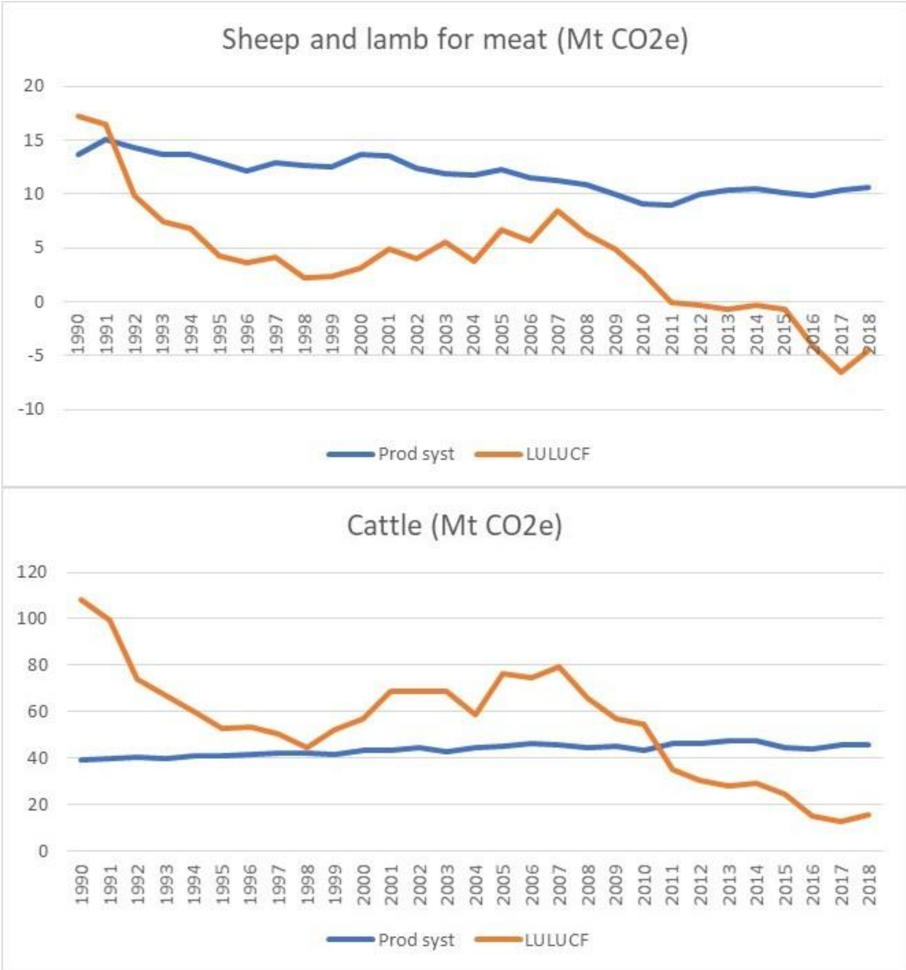


Table 1. Processes contributing to the emissions profiles of the sheep meat and beef cattle industries in 2018 assessed using the GWP100 climate metric

	Sheep meat	Beef cattle
	Mt CO_2-e	**Mt CO_2-e**
Enteric methane (pasture)	8.42	34.45
Manure management (pasture)	0.43	3.24
Agricultural soils	1.16	3.66
Liming	0.11	0.21
Urea application	0.04	0.09
Electricity and fuel (farm)	0.41	0.91
Feedlot (all emissions, excluding LULUCF)		3.18
Cropland remaining cropland		-0.14
Land converted to cropland		0.08
Cropland converted to forestland		-0.02
Grassland remaining grassland	-2.60	1.81
Land converted to grassland	4.40	31.11
Forestland remaining forestland	0.46	1.86
Grassland converted to forestland	-6.81	-19.24
Total	**6.01**	**61.22**

4.2.2 100-year Global Temperature Potential (GTP100)

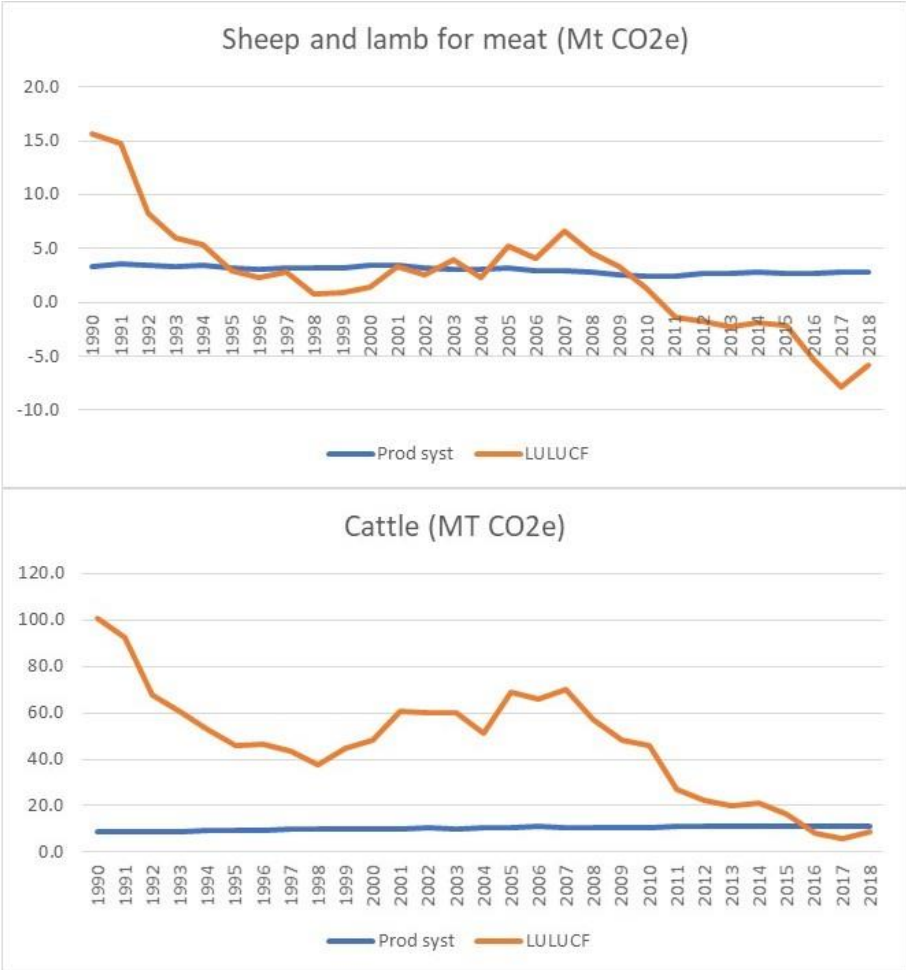
The aggregated emissions profiles for the sheep meat and beef cattle industries assessed using the GTP100 climate metric are presented in Figure 4. For the sheep meat industry, total emissions have been trending downward, from 8.4 Mt CO_2-e in the baseline year of 2005 to -3.0 Mt CO_2-e in 2018, which is a 136% reduction. Emissions are projected to remain negative at -2.4 Mt CO_2-e in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2. In 2018, the largest GHG emission source was land converted to grassland (4.29 Mt CO_2e, Table 2). The largest sink was grassland converted to forestland (-6.83 Mt CO_2-e), followed by grassland remaining grassland (-3.07 Mt CO_2-e).

For the beef cattle industry, total emissions also declined, from 79.4 Mt CO_2-e in the baseline year of 2005 to 20.1 Mt CO_2-e in 2018, which is a 75% reduction. Emissions are projected to rise marginally to 24.4 Mt CO_2-e in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2. For the beef cattle industry, it is important to note that although total emissions have fallen, production system emissions have steadily increased. In 2018, the largest GHG emission source was land converted to grassland (30.40 Mt CO_2e, Table 2). The largest sink was grassland converted to forestland (-19.29 Mt CO_2-e).

Table 2. Processes contributing to the emissions profiles of the sheep meat and beef cattle industries in 2018 assessed using the GTP100 climate metric

	Sheep meat **Mt CO_2-e**	**Beef cattle** **Mt CO_2-e**
Enteric methane (pasture)	1.20	4.92
Manure management (pasture)	0.06	0.46
Agricultural soils	1.02	3.23
Liming	0.11	0.21
Urea application	0.04	0.09
Electricity and fuel (farm)	0.41	0.91
Feedlot (all emissions, excluding LULUCF)		1.32
Cropland remaining cropland		-0.14
Land converted to cropland		0.08
Cropland converted to forestland		-0.02
Grassland remaining grassland	-3.07	-1.25
Land converted to grassland	4.29	30.40
Forestland remaining forestland	-0.21	-0.86
Grassland converted to forestland	-6.83	-19.29
Total	**-2.98**	**20.07**

Figure 4. Aggregated emissions profiles for the sheep meat and beef cattle industries assessed using the GTP100 climate metric



4.2.3 Global Temperature change Potential in year 2100 (GTP2100)

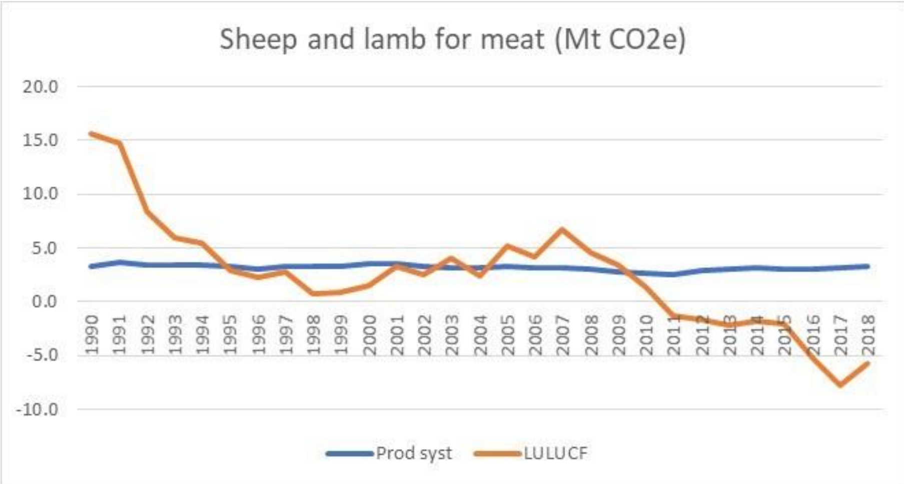
The aggregated emissions profiles for the sheep meat and beef cattle industries assessed using the GTP2100 climate metric are presented in Figure 5. The results were like those obtained using the GTP100 climate metric. For the sheep meat industry, total emissions have been trending downward, from 8.6 Mt CO_2-e in the baseline year of 2005 to -2.5 Mt CO_2-e in 2018, which is a 129% reduction. Emissions are projected to remain negative at -1.6 Mt CO_2-e in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2. In 2018, the largest GHG emission source was land converted to grassland (4.30 Mt CO_2e, Table 3). The largest sink was grassland converted to forestland (-6.82 Mt CO_2-e), followed by grassland remaining grassland (-3.04 Mt CO_2-e).

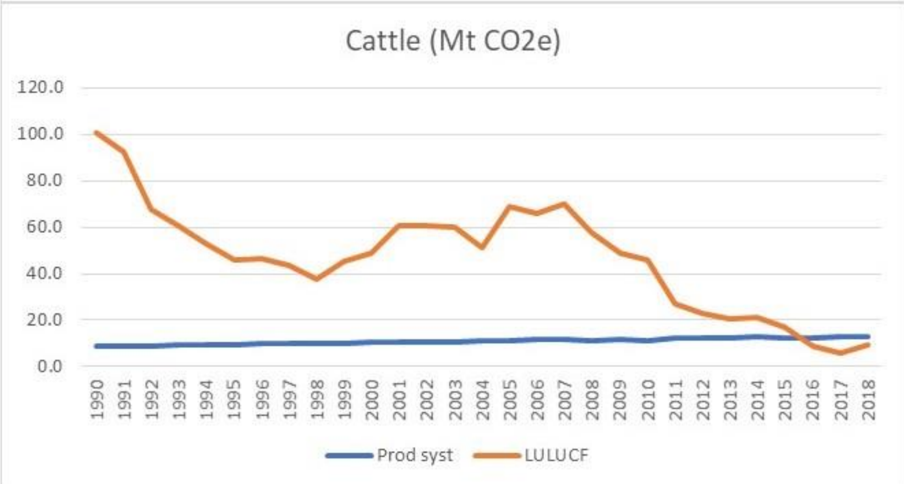
For the beef cattle industry, total emissions also declined, from 80.2 Mt CO_2-e in the baseline year of 2005 to 22.3 Mt CO_2-e in 2018, which is a 72% reduction. Emissions are projected to rise to 29.8 Mt CO_2-e in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2. For the beef cattle industry, it is important to note that although total emissions have fallen, production system emissions have steadily increased. In 2018, the largest GHG emission source was land converted to grassland (30.45 Mt CO_2e, Table 3). The largest sink was grassland converted to forestland (-19.28 Mt CO_2-e).

Table 3. Processes contributing to the emissions profiles of the sheep meat and beef cattle industries in 2018 assessed using the GTP2100 climate metric

	Sheep meat	**Beef cattle**
	Mt CO_2-e	**Mt CO_2-e**
Enteric methane (pasture)	1.51	6.19
Manure management (pasture)	0.08	0.58
Agricultural soils	1.11	3.50
Liming	0.11	0.21
Urea application	0.04	0.09
Electricity and fuel (farm)	0.41	0.91
Feedlot (all emissions, excluding LULUCF)		1.47
Cropland remaining cropland		-0.14
Land converted to cropland		0.08
Cropland converted to forestland		-0.02
Grassland remaining grassland	-3.04	-1.05
Land converted to grassland	4.30	30.45
Forestland remaining forestland	-0.18	-0.72
Grassland converted to forestland	-6.82	-19.28
Total	**-2.49**	**22.28**

Figure 5. Aggregated emissions profiles for the sheep meat and beef cattle industries assessed using the GTP2100 climate metric





4.2.4 Global Warming Potential (star) (GWP*)

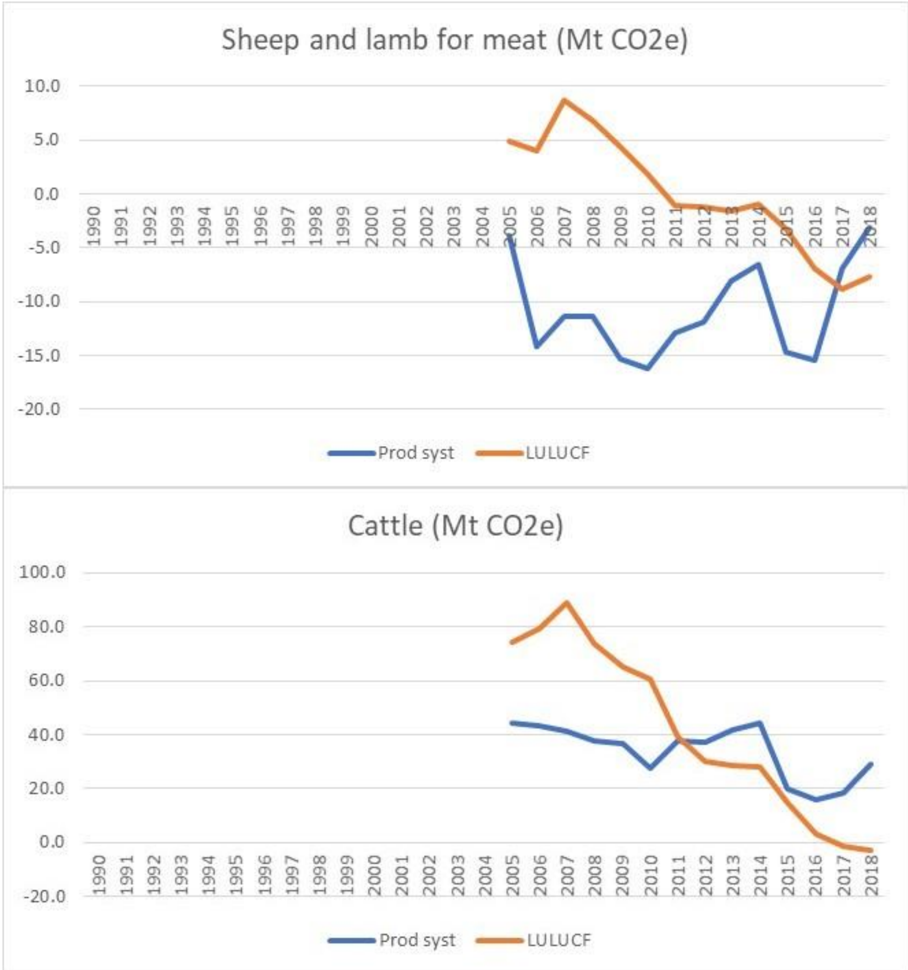
The aggregated emissions profiles for the sheep meat and beef cattle industries assessed using the GWP* climate metric are presented in Figure 6. For the sheep meat industry, total emissions have been trending downward, from 1.0 Mt CO_2-e in the baseline year of 2005 to -10.7 Mt CO_2-e in 2018. The contribution from the production system was negative across this period, although up and down. In 2018, the contribution from enteric methane was -4.52 Mt CO_2-e (Table 4), reflecting the cooling impact of a decreasing rate of methane emission. Emissions are projected to remain negative at -15.4 Mt CO_2-e in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2. In 2018, the largest GHG emission source was agricultural soils (1.16 Mt CO_2e, Table 4).

For the beef cattle industry, total emissions also declined, from 118.6 Mt CO_2-e in the baseline year of 2005 to 26.1 Mt CO_2-e in 2018. Emissions are projected to rise to 52.4 Mt CO_2-e in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2. In 2018, the contribution from enteric methane was 15.98 Mt CO_2-e (Table 4), reflecting the gradually increasing rate of methane emissions (Figure 2). The GWP* calculation is sensitive to the rate of change in methane emission and the results obtained showed potential for a high degree of volatility.

Table 4. Processes contributing to the emissions profiles of the sheep meat and beef cattle industries in 2018 assessed using the GWP* climate metric

	Sheep meat **Mt CO_2-e**	**Beef cattle** **Mt CO_2-e**
Enteric methane (pasture)	-4.52	15.98
Manure management (pasture)	-0.24	2.54
Agricultural soils	1.16	3.66
Liming	0.11	0.21
Urea application	0.04	0.09
Electricity and fuel (farm)	0.41	0.91
Feedlot (all emissions, excluding LULUCF)		5.47
LULUCF	-7.66	-2.75
Total	**-10.71**	**26.11**

Figure 6. Aggregated emissions profiles for the sheep meat and beef cattle industries assessed using the GWP* climate metric



4.2.5 75-year Combined Global Temperature change Potential (CGTP75)

The aggregated emissions profiles for the sheep meat and beef cattle industries assessed using the CGTP75 climate metric are presented in Figure 7. The results were like those obtained using the GWP* climate metric. For the sheep meat industry, total emissions have been trending downward, from -7.6 Mt CO_2-e in the baseline year of 2005 to -18.9 Mt CO_2-e in 2018. The contribution from the production system was negative across this period, although up and down. In 2018, the contribution from enteric methane was -10.75 Mt CO_2-e (Table 5), reflecting the cooling impact of a decreasing rate of methane emission. Emissions are projected to remain negative at -25.6 Mt CO_2-e in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2. In 2018, the largest GHG emission source was agricultural soils (1.14 Mt CO_2e, Table 4).

For the beef cattle industry, total emissions also declined, from 122.4 Mt CO_2-e in the baseline year of 2005 to 11.9 Mt CO_2-e in 2018. Emissions are projected to rise to 48.9 Mt CO_2-e in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2. In 2018, the contribution from enteric methane was 9.74 Mt CO_2-e (Table 5), reflecting the gradually increasing rate of methane emissions (Figure 2). The CGTP75 calculation is sensitive to the rate of change in methane emission and the results obtained showed potential for a high degree of volatility.

Figure 7. Aggregated emissions profiles for the sheep meat and beef cattle industries assessed using the CGTP75 climate metric

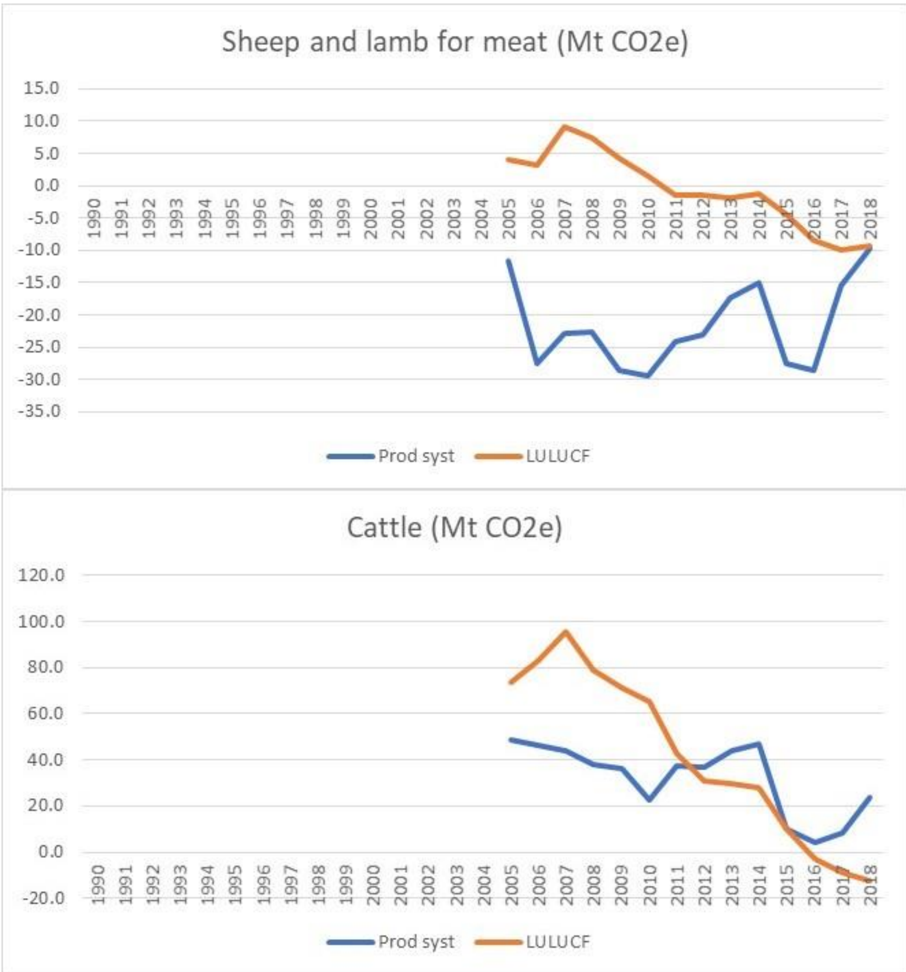


Table 5. Processes contributing to the emissions profiles of the sheep meat and beef cattle industries in 2018 assessed using the CGTP climate metric

	Sheep meat **Mt CO_2-e**	**Beef cattle** **Mt CO_2-e**
Enteric methane (pasture)	-10.75	9.74
Manure management (pasture)	-0.57	2.54
Agricultural soils	1.14	3.59
Liming	0.11	0.21
Urea application	0.04	0.09
Electricity and fuel (farm)	0.41	0.91
Feedlot (all emissions, excluding LULUCF)		6.97
LULUCF	-9.23	-12.10
Total	**-18.86**	**11.95**

4.2.6 Radiative forcing climate footprint (RF footprint)

The radiative forcing (RF) footprints of the sheep meat and beef cattle sectors are presented in Figures 8 and 9. RF footprints combine the RF from current year emissions with the RF from historical emissions that remain in the atmosphere. For the sheep meat industry, total RF (production system and land use) was 1.02 mW/m^2 in 2005 and peaked in 2009 at 1.10 mW/m2. Since 2009, the industry's RF footprint has been in decline, reaching 1.07 mW/m^2 in 2018 and projected to reach 0.92 mW/m^2 in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2. Figure 8 also shows that the sheep meat industry's incremental contribution to RF (compared to previous year) was 0.032 mW/m^2 in 2005, declining to -0.004 mW/m^2 in 2018 and projected to reach -0.015 mW/m^2 in 2030. In other words, the sheep meat sector is currently reducing its overall contribution to radiative forcing, which could be described as climate neutral or even climate cooling.

For the beef cattle industry, total RF (production system and land use) was 4.57 mW/m^2 in 2005, increasing to 5.88 mW/m^2 in 2018 and projected to reach 6.40 mW/m^2 in 2030 based on the assumptions used to extrapolate emissions described in Subsection 3.2 (Figure 9). However, the beef cattle industry's incremental contribution to RF (compared to previous year) has declined markedly, from 0.215 mW/m^2 in 2005 to 0.027 mW/m^2 in 2018. In other words, the beef cattle sector continues to make a contribution to a rising level of global RF. However, the incremental contribution is declining, and the industry is within sight of becoming climate neutral, like the sheep meat industry.

Taking the sheep meat and beef cattle industries together, the incremental contribution to RF in 2005 was 0.248 mW/m^2. This has declined by 91% to 0.023 mW/m^2 in 2018.

Figure 8. Radiative forcing (RF) footprint profiles for the sheep meat industry: historical data 1990 to 2018 and projected data to 2030

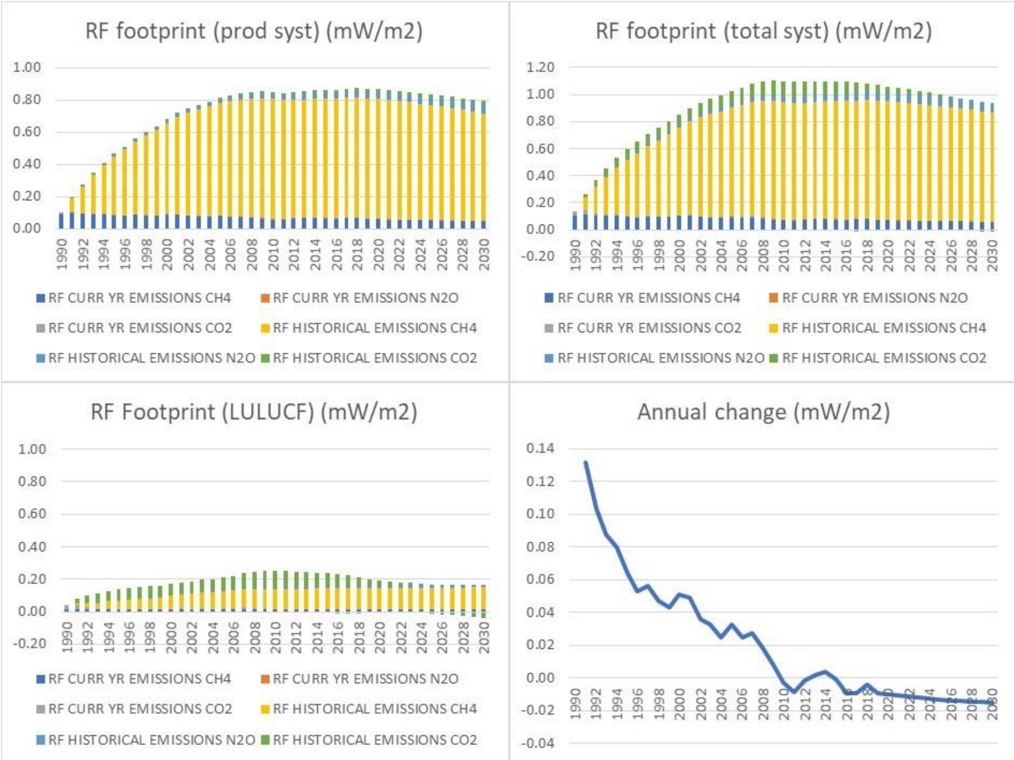
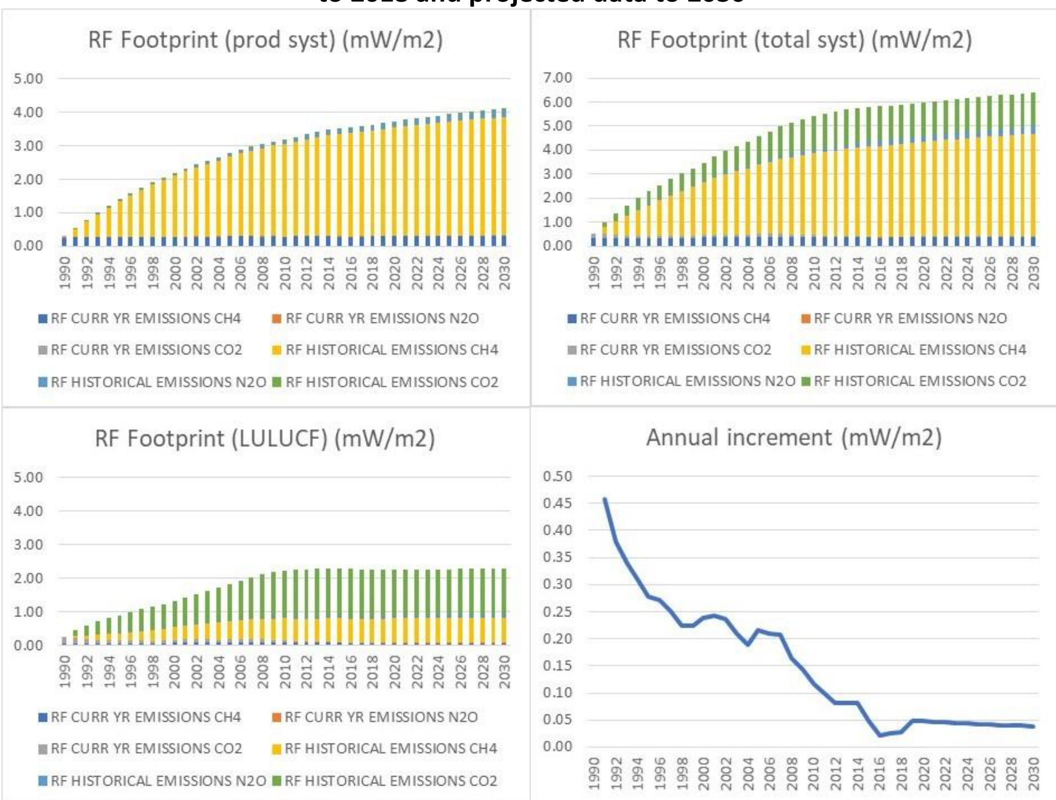


Figure 9. Radiative forcing (RF) footprint profiles for the beef cattle industry: historical data 1990 to 2018 and projected data to 2030



5. Conclusion

5.1 Key findings

It is important to acknowledge that there is no universally correct way of aggregating a basket of different GHG emissions and reporting the combined climate impact. The impacts differ over time and different climate metrics each offer a perspective. When emissions of different GHGs are aggregated, the priority should be to select an approach that is relevant to the strategic goal.

The third objective of this study was to identify potential implications of alternative climate metrics with respect to the adoption of a climate neutral target for the industry and mitigation strategies. Here it is important to note that the term “climate neutral” is currently without official definition. While the term has the potential to be used as a synonym of “carbon neutral”, there is also potential for the term to be used in the context of climate stabilization, recognizing that:

- To stabilize the climate, net zero is necessary for long-lived GHGs
- However, a more-or-less stable emissions trajectory of a short-lived GHG is compatible with climate stabilization.

The goal of climate stabilization is interpreted from Article 2 of the Paris Agreement that describes the goal of limiting the increase in global mean temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C. In simple language, the goal is not to allow global mean temperatures to keep increasing indefinitely, and nor is it to pursue efforts to return the climate to a pre-industrial condition. The 1.5 and 2 °C targets should be understood as politically agreed target that aim to reduce the risks and impacts of climate change.

For the adoption of a climate neutral target that is aligned with the goal of climate stabilization, there are three relevant GHG assessment and reporting options: GWP*, CGTP75 and RF footprint:

- GWP*: This climate metric establishes equivalence between pulses of long-lived GHGs and changes in the rate of emissions of short-lived GHGs (i.e. methane). In doing so, the profile of change in RF over time is approximated. The major strength of this metric (compared to the following two options) is that it is now well established in the scientific literature and is becoming increasingly well-known across industries with substantial short-term emissions. One major drawback is the rather bumpy profile that is demonstrated in Figure 6. This is a consequence of the need to discern the permanent rate of change in methane emission, which is difficult due to the variability in agricultural emissions from year to year. The bumpy nature of results from year to year could present challenges for communication with stakeholders. The other major drawback is that the recently developed CGTP and CGWP climate metrics appear to be methodologically superior (Collins et al., 2020).
- CGTP75: This climate metric shares the same conceptual basis as the GWP*, establishing equivalence between pulses of long-lived GHGs and changes in the rate of emissions of short-lived GHGs (i.e. methane). The authors of the metric (Collins et al., 2020) present several options (CGWP50, CGWP75, CGWP100, CGTP50, CGTP75, CGTP100), but recommend CGTP75 as the most relevant in the context of the Paris Agreement. The metric is less well known, but that could change soon. It also has the same drawback of producing a rather bumpy profile over time (Figure 7). There is also a sense in which the metric can be somewhat difficult to explain, being based on pulses and rate changes, and relating to a climate target 75 years into the future.
- RF footprint: This approach to aggregating emissions also takes into account the differences in impacts over time of long- and short-lived GHGs. However, it does so without explicitly introducing the pulse and rate change nomenclature. As shown in this study, the results obtained are less perturbed by annual fluctuations in emissions (Figures 8 and 9), which

could be an advantage for communication. The approach also provides for highly visual performance tracking, which could also be an advantage for communication. Apart from this, the approach is not yet widely known, but this could change in the future. An ISO document (ISO/TR 14082) is currently in development. The results are potentially easier to explain as they relate to a present reality.

The adoption of a climate neutral target by the Australian red meat industry could have important implications for GHG mitigation strategy. Mitigation strategies will always be beneficial if they reduce costs and risks and do not lead to environmental trade-offs.

However, strategies that achieve methane emission reductions but lead to increased long-lived GHG emissions require scrutiny. Such strategies may provide a short-term climate benefit. However, by increasing persistent long-lived emissions, these strategies may make the goal of climate stabilization more difficult in the medium to long term.

It is possible, that the current use of the GWP100 climate metric has led to an over-emphasis on methane reduction strategies. Under a climate neutral approach, methane emissions need to be more-or-less stabilized. It is the long-lived emissions (CO_2, N_2O) that need to be reduced to net zero. In the near term, climate neutrality can be attained through reductions in methane emissions that compensate for ongoing net CO_2 and N_2O emissions (as demonstrated for Australian sheep meat production). Ongoing permanent reductions in rate of methane emission cannot be sustained indefinitely, so strategies will be needed to address CO_2 and N_2O.

Under a climate neutrality approach, there is no requirement for methane emissions to be reduced to zero or otherwise offset. As such, technologies that can reduce methane emissions will create scope for the industry to grow and remain an important contributor of nutrient-dense foods within the food system.

Recommendations are reported in Section 6, below.

5.2 Benefits to industry

The adoption of a climate neutral target could have important implications for GHG mitigation strategy, as there is no requirement for methane emissions to be reduced to zero or otherwise offset. There could be a need to give greater emphasis to strategies for the mitigation of long-lived GHG emissions (CO2 and N2O). The report also highlights the potential dangers of strategies that seek to mitigate methane emissions but lead to higher CO2 and N2O emissions.

Positively, there is evidence that the sheep meat industry is already climate neutral, and the beef cattle industry is not far away from this goal.

Under the kind of climate neutral strategy described in this report, technologies that reduce methane emissions can create scope for the industry to grow sustainably.

6. Future research and recommendations

The current GHG emissions inventory for the production system has a system boundary that is unusual and not clearly justified. Emissions are excluded that have potential relevance in mitigation strategies.

Recommendation 1: Undertake a review of the inventory method for the production system and explore the potential for including emissions related to fertilizer production, supplementary feed used on farm, and transportation processes.

LULUCF emissions and sequestrations are large and have a major bearing on overall results, yet they appear poorly documented and highly uncertain.

Recommendation 2: Continue to advance methods to reduce the uncertainties in LULUCF emission estimates.

Recommendation 3: Undertake a thorough assessment of the LULUCF category, document individual sources and sinks and assess whether they are inherently a part of the activity of producing livestock, or separate activities under the direct management of the industry, or related to natural processes or processes managed by others.
The industry's GHG mitigation strategy should be informed by a detailed model that can quantify the impacts of interventions on future emissions under realistic scenarios.

Recommendation 4: Develop a detailed process-based systems model that can be used to quantify future emissions under a variety of realistic scenarios

For any industry with substantial short-lived GHG emissions, a net zero GHG emission target generally exceeds the climate stabilization aspiration of the Paris Agreement, with likely economic and social cost.

Recommendation 5: MLA should consult with stakeholders about the formal adoption of a GHG emissions reduction commitment that is aligned with the Paris Agreement and consider the options outlined in Section 5.
"Climate neutrality" is an emerging concept but is not formally defined.

Recommendation 6: MLA should explore with CSIRO options for formalising the definition and quantification of "climate neutrality"

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.

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.

Allen, M.R., Shine, K.P., Fuglestvedt, J.S., Millar, R.J., Cain, M., Frame, D.J., Macey, A.H., 2018. A solution to the misrepresentations ofCO2-equivalent emissions of shortlived climate pollutants under ambitious mitigation Clim. Atmos. Sci. 1 16.

Collins, W.J., Frame, D.J., Fuglestvedt, J.S., Shine, K.P., 2020. Stable climate metrics for emissions of short and long-lived species – combining steps and pulses. Environ. Res. Lett. 15, 024018.

DISER, 2020a. Activity Table 1990-2018 - Agriculture – Livestock National. Canberra: Australian Government Department of Science, Industry, Energy and Resources. https://ageis.climatechange.gov.au/QueryAppendixTable.aspx

DISER, 2020b. National Inventory Report 2018 Volume 1. Canberra: Australian Government Department of Industry, Science, Energy and Resources.

DISER, 2020c. National Inventory Report 2018 Volume 2. Canberra: Australian Government Department of Industry, Science, Energy and Resources.

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, 2018. Short-Lived Climate Forcers (SLCF). Eds: Blain, D., Calvo Buendia, E., Fuglestvedt, J.S., Gómez, D., Masson-Delmotte, V., Tanabe, K., Yassaa, N., Zhai, P., Kranjc, A., Jamsranjav, B., Ngarize., S., Pyrozhenko, Y., Shermanau, P., Connors, S. and Moufouma-Okia, W. Report of the Expert Meeting on Short-Lived Climate Forcers, Pub. IGES, Japan.

ISO, 2021. 14082 Radiative forcing management – Quantification and reporting of radiative forcing climate footprints and mitigation efforts, Working Draft 001, N66. Geneva: International Organisation for Standardization.

Mayberry, D., Bartlett, H., Moss, J., Wiedemann, S., Herrero, M. 2018. Greenhouse gas mitigation potential of the Australian red meat production and processing sectors. North Sydney: Meat and Livestock Australia. https://www.mla.com.au/research-and-development/search-rd-reports/final-report-details/Greenhouse-gas-mitigation-potential-of-the-Australian-red-meat-production-and-processing-sectors/3726

Myhre, G., Shindell, D., Bréon, F.-M., et al., 2013. Chapter 8, Anthropogenic and natural radiative forcing. In: Stocker, T.F., et al. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 659-740.

Ridoutt, B. 2021. Climate neutral livestock production - A radiative forcing-based climate footprint approach. J. Clean. Prod. 291, 125260.

Ridoutt, B., Huang, J. 2019. When climate metrics and climate stabilization goals do not align. Environ. Sci. Technol. 53(24): 14093–14094.

Smith, M.A., Cain, M., Allen, M.R., 2021. Further improvement of warming-equivalent emissions calculation. Clim. Atmos. Sci. 4 19.

United Nations Treaty Collection, Paris Agreement 2015. https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en (accessed 4 May 2020).

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. Anim. Prod. Sci. 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. Int. J. Life Cycle Assess. 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. Anim. Prod. Sci. 56: 1070-1080.

8 Appendix

8.1 Methods for allocating emissions from the National Greenhouse Gas Inventory

Emissions source	Allocation to red meat
Agriculture	
Enteric fermentation	All emissions from beef cattle in feedlots and beef cattle on pasture were reported directly from the National Inventory. Emissions from sheep were attributed to meat production following Wiedemann et al. (2015). Emissions from all other livestock were excluded.
Manure management	All emissions from beef cattle in feedlots and beef cattle on pasture were reported directly from the National Inventory. Emissions from sheep were attributed to meat production following Wiedemann et al. (2015). Emissions from all other livestock were 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 were reported directly from the National Inventory. Emissions from sheep were attributed to meat production following 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 attributed to meat production following 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 above.
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). The quantity of lime used for sheep farming was attributed to meat production following 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). The quantity of lime used for sheep farming was attributed to meat production following 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. Emissions relating to dairy cattle were excluded.

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).