Final report

Pathways to climate neutrality for the Australian red meat industry

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Abstract

The purpose of this project was to identify and evaluate pathways for the Australian Red Meat Industry to become climate neutral, whereby the radiative forcing (RF) footprint is stabilised or there is no net contribution to future warming. An inventory of emissions was compiled from 1990 to 2020 that was extrapolated to 2030. Scenario analysis was used to identify pathways to climate neutrality utilizing a portfolio of greenhouse gas (GHG) emission reduction and sequestration interventions. Emission reduction interventions included feed additives, forage crops, breeding for lower methane, and improved herd/flock management. Vegetation management interventions included trees on farm, soil carbon storage, and savannah burning management. With business as usual, the GHG footprint increases from 51.3 Mt CO_2e in 2020 to 63.5 Mt CO_2e in 2030. Combining all interventions enabled the GHG footprint to reach 17.3 Mt CO_2e. More than 80% of GHG reductions were related to vegetation management. In contrast, the industry has the potential to become climate neutral in 2026. Climate neutrality appears realistically achievable, with successful deployment of emission reduction and sequestration strategies providing scope for industry growth. This approach is based on IPCC science and is well aligned with the climate stabilisation goal of the Paris Agreement.

Executive summary

Background

The purpose of this project was to identify and evaluate pathways for the Australian Red Meat Industry to become climate neutral. Here, climate neutral refers to a status whereby the radiative forcing (RF) footprint is stabilised or there is no net contribution to future warming.

Climate neutrality involves the management of emissions to achieve climate stabilisation. This approach acknowledges that different targets are needed for different types of emissions. For a greenhouse gas (GHG) with a long atmospheric lifetime, such as carbon dioxide (CO_2), reaching net zero is necessary. However, for a GHG with a short atmospheric lifetime, such as methane (CH_4), a modestly declining emissions trajectory is consistent with climate stabilisation.

This distinction is most important for the Australian Red Meat Industry since biogenic methane is an important proportion of total GHG emissions.

This approach differs from carbon neutrality, which usually involves reducing all GHG emissions to net zero.

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 many stakeholders engaged in these decisions.

Objectives

The objective was to identify pathways to achieve and maintain a climate neutral target by the Australian Red Meat Industry in the time horizon to 2030.

This objective was successfully met.

In a separate report, an updated GHG footprint for the Australian Red Meat Production and Processing Sectors for the year 2020 is presented.

Methodology

The method involved three steps:

1. Extrapolate the emissions timeseries (1990 to 2020) to 2030 using industry projections for livestock numbers and production
2. Compile a portfolio of GHG emission reduction and sequestration options, along with their potential efficacy and adoption
3. Use scenario analysis to identify pathways for the industry to become climate neutral on or before 2030

As a point of reference, the GHG footprint was also assessed using the GWP100 climate metric.

Results/key findings

With business as usual, the GHG footprint of the Australian Red Meat Industry, assessed using the GWP100 climate metric, increased from 51.3 Mt CO_2e in 2020 to 63.5 Mt CO_2e in 2030. Combining all interventions enabled the net GHG emissions to be reduced to 17.3 Mt CO_2e. More than 80% of GHG emission reductions were related to vegetation management, i.e., trees on farm, soil carbon sequestration, and savannah burning management. While this is a substantial GHG emissions reduction, achieving CN30 (net zero GHG emissions) will require actions exceeding those modelled in this study.

In contrast, the industry has the potential to become climate neutral by 2026. This is also possible for the beef cattle and sheep meat sectors individually. The feedlot sector has the potential to achieve climate neutrality in 2028.

Climate neutrality appears realistically achievable and with successful deployment of emission reduction and sequestration strategies there is scope for future industry growth.

The climate neutral approach is based on IPCC science and is well aligned with the climate stabilisation goal of the Paris Agreement.

Benefits to industry

For an industry with substantial biogenic methane emissions, a net zero GHG emission target generally exceeds the climate stabilisation aspiration of the Paris Agreement, with likely economic and social cost. The results obtained in this project can be used to support the formal adoption of a climate neutral target by the Australian Red Meat Industry.

The adoption of an industry climate neutral target would not preclude individual red meat producers or processors also participating in GWP100-based frameworks, reporting schemes, and labelling programmes.

Future research and recommendations

The report makes four recommendations that relate to:

1. Data collection to enable climate actions to be recognised in the annual Red Meat Industry GHG footprint
2. Actions to formalise the terminology and quantification methods for climate neutrality
3. Modelling to evaluate alternative RF stabilization targets for the industry
4. Method development to support application of the climate neutral approach to individual producers and products

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1. Background

The Australian red meat industry is a source of 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. This complicates the development of multi-gas climate action strategies.

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. Each climate metric uses a different basis for comparison; for example, by estimating the relative climate impact at a certain future point in time, or over a chosen interval of time. Critically, 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 includes the Australian Red Meat Industry's CN30 strategy and annual reporting (Mayberry 2022, Ridoutt 2022). However, in recent years there has been a renewed interest in the use of alternative climate metrics in relation to short-lived GHG emissions, particularly biogenic methane. For the livestock industries, the application of alternative climate metrics can have profound implications for GHG emissions abatement strategy and reporting (Ridoutt 2021a, 2021b)

The need to apply different strategies for the management of short-lived GHG emissions (e.g., methane) compared to long-lived GHG emissions (e.g., CO_2) is now widely acknowledged, as reported by the IPCC Working Group 1 Co-Chair (IPCC 2021):

> *"Stabilizing the climate will require strong, rapid, and sustained reductions in greenhouse gas emissions, and reaching net zero CO_2 emissions. Limiting other greenhouse gases and air pollutants, especially methane, could have benefits both for health and the climate," said Zhai.* [Emphasis added]

These alternative climate metrics are especially relevant to the ruminant livestock industries because biogenic methane is one of the main greenhouse gases. Recently, an assessment of alternative climate accounting metrics for the Australian Red Meat Industry was undertaken (MLA Project B.CCH.2117; Ridoutt and Mayberry 2021). This study highlighted the opportunity to adopt a climate neutral target based on either the GWP* climate metric or the radiative forcing climate footprint (RF footprint).

The application of alternative climate metrics is also being explored by FAO (2022), the Global Dairy Platform (Cady 2020), and beef cattle industries in the US (Place and Mitloehner 2021) and elsewhere (Allen et al. 2022).

Scoping work has already been undertaken in Australia for sheep meat and other livestock production (Ridoutt 2021a, 2021b) and in relation to seaweed feed supplementation (Ridoutt et al. 2022). However, a wider evaluation of actions that could enable attainment and maintenance of a climate neutral position is yet to be undertaken and is an important gap.

The purpose of this project was to identify and evaluate pathways for the Australian Red Meat Industry to become climate neutral. Here, climate neutral refers to a status whereby the radiative forcing (RF) footprint is stabilised or there is no net contribution to future warming.

Climate neutrality involves the management of emissions to achieve climate stabilisation. This approach acknowledges that different targets are needed for different types of emissions. For a greenhouse gas (GHG) with a long atmospheric lifetime, such as carbon dioxide, reaching net zero is necessary. However, for a GHG with a short atmospheric lifetime, such as methane, a modestly declining emissions trajectory is consistent with climate stabilisation.

This approach differs from carbon neutrality, which usually involves reducing all GHG emissions to net zero.

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 many stakeholders engaged in these decisions.

2. Objectives

The objective of this project was to identify pathways to achieve and maintain a climate neutral target by the Australian Red Meat Industry in the time horizon to 2030.

This follows the separate reporting of an updated GHG footprint for the Australian Red Meat Production and Processing Sectors extending to the year 2020 (Ridoutt 2022).

All objectives were successfully met.

3. Methodology

3.1 Disaggregated timeseries of GHG emissions

Disaggregated timeseries of GHG emissions (CO_2, N_2O and CH_4), covering beef cattle production (including feedlot finishing), sheep meat production, goat production, and red meat processing, were compiled for the years 1990 to 2020. Data for the period 2005 to 2020 were obtained directly from Ridoutt (2022). Using identical methods, data covering the period 1990 to 2004 were also compiled. This approach utilised data predominantly sourced from Australia's National Greenhouse Gas Inventory (**ageis.climatechange.gov.au/**; DISER 2022a, 2022b). A detailed description of the system boundary, allocation procedures, and other modelling decisions is reported in Ridoutt (2022).

3.2 Extrapolation of emissions to 2030

The disaggregated timeseries of GHG emissions were extrapolated to 2030 using estimates and forecasts for livestock numbers and production supplied by MLA. To ensure consistency with the historical data used in Section 3.1, percentage increases were applied. For example, MLA estimate an increase in the number of sheep and lamb of 10% from 2020 to 2021 (MLA 2022b) and an increase in the number of cattle of 6% from 2020 to 2021 (MLA 2022a). Therefore, the livestock numbers and their associated emissions were increased by 10 and 6% accordingly. In the case of goat production, livestock numbers were assumed to remain the same through to 2030 as they were during the period 2016 to 2020.

The livestock and production forecasts used to extrapolate GHG emissions to 2030 are presented in Table 1. As shown, sheep and lamb numbers are forecast to increase by almost 18% to more than 78 million head in 2030. For beef cattle, the increase is almost 13% to 23.9 million head in 2030, with the feedlot sector increasing at a similar rate to around 400 million head days. The processing of mutton and lamb is also forecast to increase by more than 17% to around 774 thousand t HSCW. For beef cattle, processing is forecast to increase by a similar level to more than 2.4 million t HSCW.

Table 1. Livestock and production forecasts used to extrapolate GHG emissions to 2030

Year	Goats '000 head	Sheep[1] '000 head	Cattle[2] '000 head	Feedlot[3] Million head days	Processing - beef cattle '000t HSCW[4]	Processing - mutton/lamb '000t HSCW[4]
2020	460	66,670	21,228	356	2,083	658
2021	460	73,545	22,512	348	1,872	663
2022	460	79,196	23,781	376	1,956	703
2023	460	82,036	24,747	388	2,162	746
2024	460	82,616	24,888	395	2,295	734
2025	460	83,376	24,683	396	2,330	742
2026	460	81,822	24,422	397	2,347	748
2027	460	80,333	24,144	397	2,361	755
2028	460	78,842	23,884	398	2,377	762
2029	460	78,654	23,840	399	2,392	768
2030	460	78,529	23,905	401	2,420	774

[1] Includes lambs; [2] Cattle on pasture; [3] Feedlot cattle; [4] Hot Standard Carcase Weight

3.3 Mitigation and sequestration interventions

In consultation with MLA, a list of GHG mitigation and sequestration strategies was compiled (Table 2). These strategies are at various stages of technological development and adoption. Only strategies with a realistic potential for adoption prior to 2030 were considered, in line with the time horizon of this study. These strategies cover feed additives, forage crops, breeding for lower enteric methane emissions, and improved herd/flock management. Vegetation management interventions included trees on farm, soil carbon storage, and savannah burning management.

For production system interventions, estimates of efficacy and adoption were obtained from recent reviews (Hegarty et al. 2021, Black et al. 2021, Almeida et al. 2021, Fouts et al. 2022). Individual studies may show greater impacts than those shown in Table 2. For example, in vitro studies simulating rumen digestion have demonstrated up to 99% reduction in methane formation by *Asparagopsis* macroalgae (Machado et al. 2014, Brooke et al. 2020, Kinley et al. 2016), and controlled feeding experiments have also shown very large reductions in some situations (Roque et al. 2021, Kinley et al. 2020). However, average values obtained from reviews were used as these are potentially more likely to reflect typical performance when widely deployed in a range of settings, and often under less-than-optimal conditions. Where additional assumptions were made, these are described in Table 2.

For vegetation management, the assumed adoption rate was based on published industry targets (MLA 2021a, 2021b).

Increases in adoption between 2023 and 2030 were assumed to follow an approximate S-shaped adoption curve (Table 3).

Table 2. Compilation of GHG mitigation and sequestration interventions

Intervention	Sector	Efficacy	Adoption (initial)	Adoption (2030)	Notes
High impact feed additive	Feedlot	49%	2023 – 5%	80%	Includes Bovaer® (3-NOP) as well as additives derived from macroalgae. Efficacy relates to enteric methane emission reduction. Potential productivity impacts, but likely small and uncertain.
High impact feed additive	Beef cattle (grazing)	11%	2026 – 2%	30%	Methane yield reduction less for animals on forage diets and administration likely to be sub-optimal (15-30% of efficacy in feedlots).
High impact feed additive	Sheep (grazing)	11%	2026 – 2%	30%	Methane yield reduction less for animals on forage diets and administration likely to be sub-optimal (15-30% of efficacy in feedlots).
Other feed additives	Feedlot	10%	2023 – 2%	10%	Includes tannin extracts, saponins, grape marc, etc. Methane yield reduction typically < 15%. Potential impact on feed digestibility and growth, but likely small.
Other feed additives	Beef cattle (grazing)	5%	0%	0%	Given the relatively low efficacy, it is not envisaged that these products will be widely adopted in grazing systems before 2030.
Other feed additives	Sheep (grazing)	1%	2023 – 2%	10%	Grape marc might have limited potential for supplemental feeding of sheep in southern Australia located in proximity to wineries (0.10 x 10% of year).
Leucaena forage crop	Beef cattle (grazing)	2%	2023 – 2%	20%	Methane yield reduction is generally less than 15%, applicable to 20% of Australian beef cattle herd (0.10 x 20%).
Desmanthus forage crop	Beef cattle (grazing)	4%	2023 – 2%	20%	Methane yield reduction is generally less than 15%, applicable to 40% of Australian beef cattle herd (0.10 x 40%).
Breeding for lower methane emission	Beef cattle (grazing)	0.25%/yr	2023 – 1%	3%	Estimated reduction of 4-8% achievable over 20 years, may be constrained by impacts on productivity traits (5% /20 years). Adoption may be low due to testing costs.
Breeding for lower methane emission	Sheep (grazing)	0.25%/yr	2023 – 1%	3%	Estimated reduction of 4-8% achievable over 20 years, may be constrained by impacts on productivity traits (5% /20 years). Adoption may be low due to testing costs.
Trees on farm	Beef cattle (grazing) Sheep (grazing)	25 MT/y	2023 – 5%	100%	Integration of shade and shelterbelts on 10 M ha (southern Aust focus) of available 355 million ha of grazing area nationally, storing more than 25MT CO_2 per annum. Sequestration divided equally between beef cattle and sheep.
Soil carbon storage	Beef cattle (grazing)	7.8 MT/y	2023 – 5%	100%	Soil carbon storage increased via a variety of means, including planting of leguminous forage crops, fertilization of pastures, and the transition of cropland to permanent pasture. Soil carbon storage levels in 30% of grazing lands increased by 50-100 kg CO_2/ha/year (520 M ha x 30% x 50 kg/ha/yr).
Savannah burning management	Beef cattle (grazing)	10.7 MT/y	2023 – 5%	100%	More than 40 million ha of cattle grazing land can adopt savannah burning mgmt. 0.044 t CO_2e/ha/y from avoided CH_4 and N_2O emissions due to less intense burning. 0.22 t/CO_2e/ha/y from additional carbon sequestration in woody biomass.
Herd management	Beef cattle (grazing)	15%	2023 – 5%	80%	Activities including the culling of unproductive animals, supplementary feeding, and improved grazing management. Variable, but 15% reduction in methane feasible. Adoption high due to productivity co-benefits.
Herd management	Sheep (grazing)	10%	2023 – 5%	50%	Variable, but 10% reduction in methane feasible. Realistic productivity co-benefits.

Table 3. S-shaped adoption curves for high impact feed additives

Year	Feedlot % adoption	Beef cattle – pasture % adoption	Sheep - pasture % adoption
2023	5	0	0
2024	9	0	0
2025	16	0	0
2026	31	2	2
2027	54	6	6
2028	69	16	16
2029	76	26	26
2030	80	30	30

3.4 Scenario modelling

The extrapolated timeseries of emissions developed in Section 3.2 were modified according to the interventions compiled in Section 3.3. The modified timeseries were then assessed using a variety of climate metrics described below. The results were used to explore pathways for the industry to become climate neutral on or before 2030.

3.4.1 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 used (Myhre et al. 2013), with results reported as CO_2-equivalent emissions.

3.4.2 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, following Ridoutt and Mayberry (2021). The GWP* results for methane were calculated using the adjustment described by Smith et al. (2021) and using the GWP100 value of 28 for methane reported by Myhre et al. (2013). Long-lived GHG emissions, 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 3.4.1. 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.

3.4.3 RF footprint

The RF footprint combines radiative forcing from current year emissions and the radiative forcing from historical emissions remaining in the atmosphere (Ridoutt 2021b, 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). An historical time horizon of 1990 was used, consistent with the emissions timeseries reported in Section 3.1 and the National Greenhouse

Gas Inventory (DISER 2022a, 2022b). Results were reported in the units milli watts per square meter (mW/m2) of radiative forcing.

4. Results

4.1 Projected GHG footprint (GWP100)

4.1.1 Feedlot sector

Considering only the feedlot sector, GHG emissions assessed using the GWP100 climate metric (AR5), have increased from 2.2 to 2.9 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 1). Under a business-as-usual scenario, GHG emissions are projected to continue increasing and reach 3.3 Mt CO_2e in 2030. This is a consequence of the increase in cattle in feedlots described in Table 1.

However, with the adoption of high impact feed additives in feedlots, the GHG footprint of the feedlot sector has the potential to be reduced to 2.3 Mt CO_2e in 2030, a level only marginally above the level in 2005 and around 28% below the projected business-as-usual level in 2030 (Fig. 1).

In summary, the achievement of GHG neutrality (carbon neutrality) in the feedlot sector will require actions exceeding those modelled in this study (Table 2).

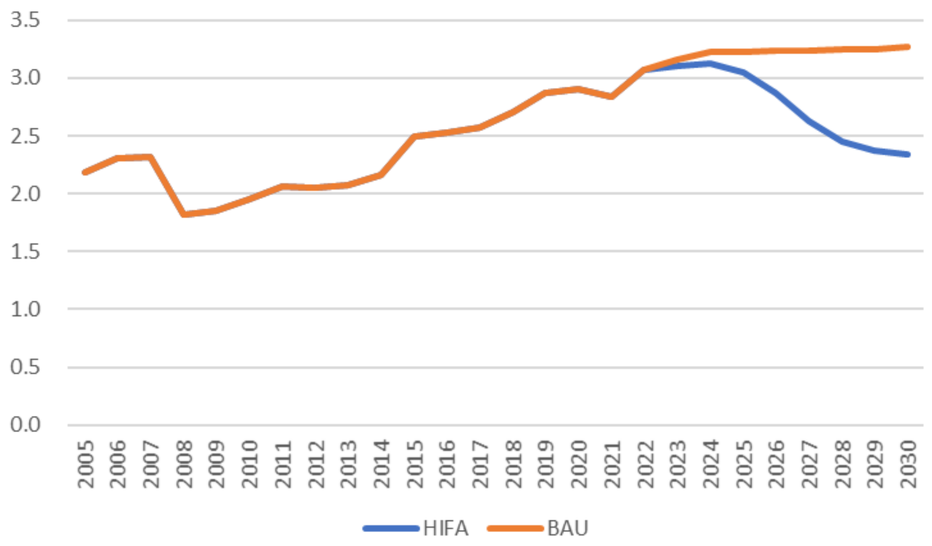

Figure 1. Feedlot sector GHG emissions assessed using the GWP100 climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of high impact feed additives (HIFA).

4.1.2 Sheep for meat (excluding LULUCF)

Considering the sheep for meat sector (excluding LULUCF; Land Use, Land-Use Change and Forestry), GHG emissions assessed using the GWP100 climate metric (AR5), have decreased from 12.3 to 9.9 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 2). Under a business-as-usual scenario, GHG emissions are projected to increase and reach 11.7 Mt CO_2e in 2030. This is a consequence of an increase in the size of the flock described in Table 1.

However, with the adoption of GHG mitigation actions, the GHG footprint of the sheep meat sector has the potential to be reduced to 11.0 Mt CO_2e in 2030, a higher level than in 2020, but around 6.6% below the projected business-as-usual level in 2030 (Fig. 2).

Regarding the projected GHG emissions reduction achieved in 2030 through climate action, the highest contribution came from improved flock management (Table 4).

In summary, the achievement of GHG neutrality (carbon neutrality) in the sheep for meat sector (excluding LULUCF) will require actions exceeding those modelled in this study (Table 2).

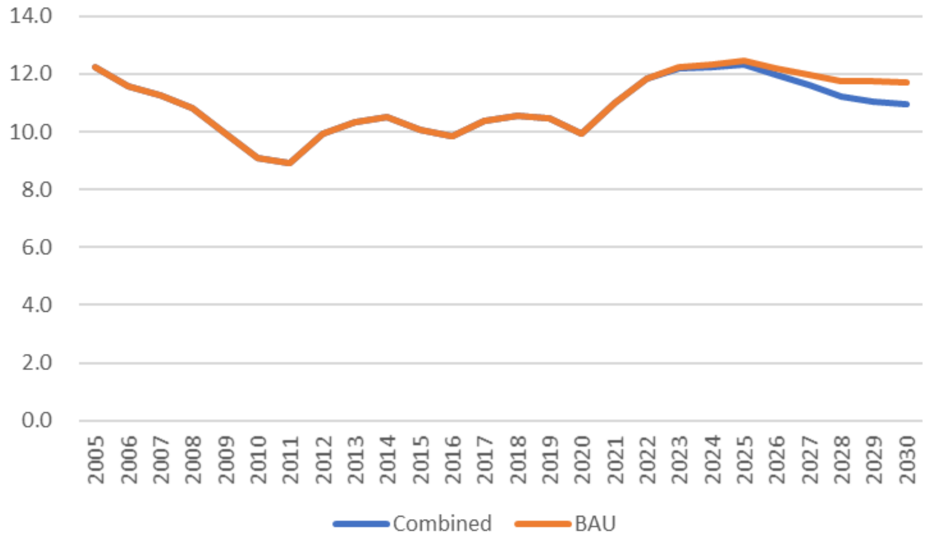

Figure 2. Sheep for meat sector (excluding LULUCF) GHG emissions assessed using the GWP100 climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of a combination of GHG mitigation actions.

Table 4. Contribution to projected GHG emissions reduction in the sheep for meat sector (excluding LULUCF) in 2030. Emissions were assessed using the GWP100 climate metric.

Climate action	Contribution to GHG emissions reduction %
Improved flock management	59.8
Feed additives – sheep pasture	39.5
Breeding for lower enteric methane emissions	0.7

4.1.3 Pasture-based beef cattle (excluding LULUCF)

Considering the pasture-based beef cattle sector (excluding LULUCF and feedlots), GHG emissions assessed using the GWP100 climate metric (AR5), have decreased from 42.9 to 38.2 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 3). Under a business-as-usual scenario, GHG emissions are projected to increase and reach 43.0 Mt CO_2e in 2030. This is a consequence of an increase in the size of the herd described in Table 1.

However, with the adoption of GHG mitigation actions, the GHG footprint of the pasture-based beef cattle sector has the potential to be reduced to 37.4 Mt CO_2e in 2030, a reduction of around 13% compared to business as usual (Fig. 3).

Regarding the projected GHG emissions reduction achieved in 2030 through climate action, the highest contribution came from improved herd management (Table 5).

In summary, the achievement of GHG neutrality (carbon neutrality) in the pasture-based beef cattle sector (excluding LULUCF) will require actions exceeding those modelled in this study (Table 2).

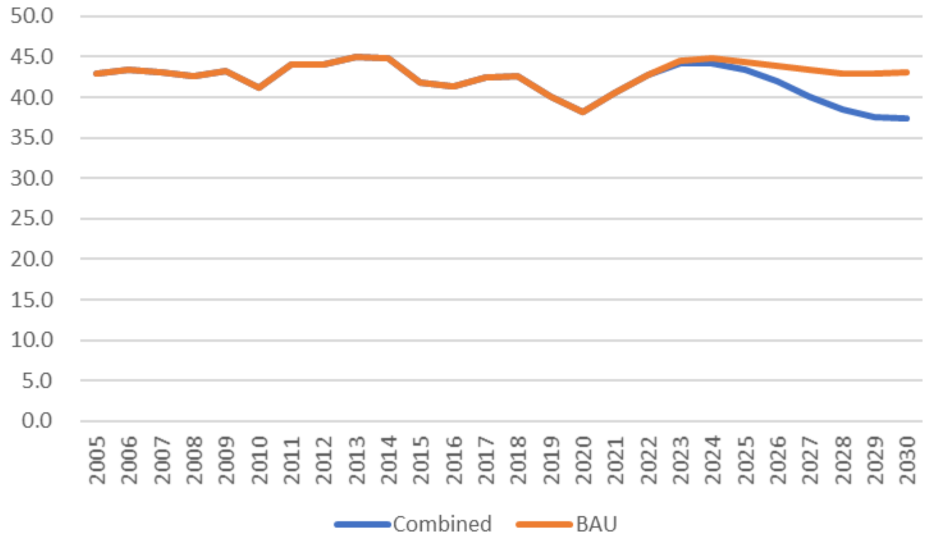

Figure 3. Beef cattle sector (excluding LULUCF) GHG emissions assessed using the GWP100 climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of a combination of GHG mitigation actions.

Table 5. Contribution to projected GHG emissions reduction in the beef cattle sector (excluding LULUCF) in 2030. Emissions were assessed using the GWP100 climate metric.

Climate action	Contribution to GHG emissions reduction %
Improved herd management	72.5
Feed additives – beef cattle pasture	19.9
Forage crops	7.2
Breeding for lower enteric methane emissions	0.4

4.1.4 Sheep for meat (including LULUCF)

Considering the sheep for meat sector (including LULUCF), GHG emissions assessed using the GWP100 climate metric (AR5), have decreased from 19.6 to 5.7 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 4). Under a business-as-usual scenario, GHG emissions are projected to increase and reach 7.0 Mt CO_2e in 2030. This is a consequence of an increase in the size of the flock described in Table 1.

However, with the adoption of GHG mitigation actions, the GHG footprint of the sheep meat sector has the potential to be reduced to -1.7 Mt CO_2e in 2030, a level consistent with the Industry's CN30 target (Fig. 4).

Regarding the projected GHG emissions reduction achieved in 2030 through climate action, the majority is attributable to planting trees on farms (> 90%; Table 6).

In summary, the achievement of GHG neutrality (carbon neutrality) in the sheep for meat sector (including LULUCF) is realistically possible but is highly dependent on tree planting.

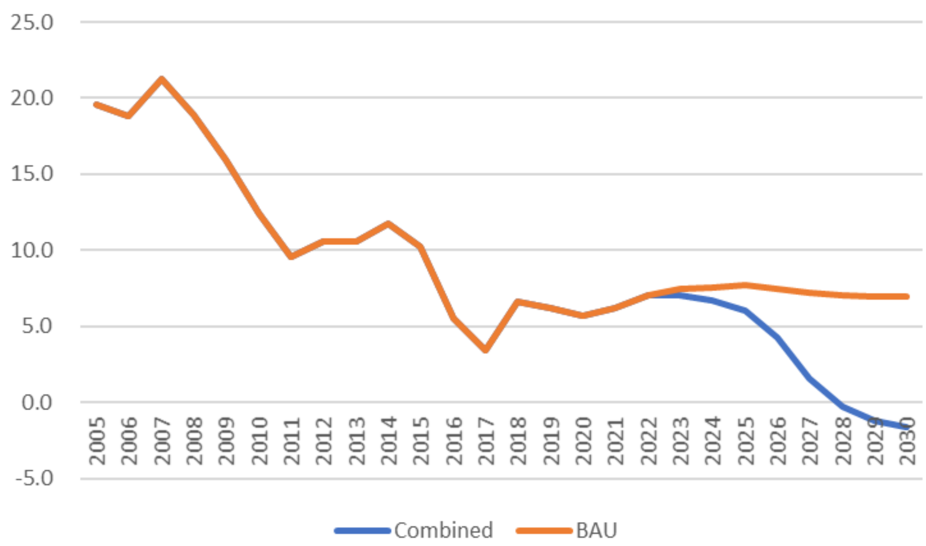

Figure 4. Sheep for meat sector (including LULUCF) GHG emissions assessed using the GWP100 climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of a combination of GHG mitigation actions.

Table 6. Contribution to projected GHG emissions reduction in the sheep for meat sector (including LULUCF) in 2030. Emissions were assessed using the GWP100 climate metric.

Climate action	Contribution to GHG emissions reduction %
Trees on farm	91.1
Improved flock management	5.3
Feed additives – sheep pasture	3.5
Breeding for lower enteric methane emissions	0.1

4.1.5 Beef cattle (including feedlots and LULUCF)

Considering the beef cattle sector (including feedlots and LULUCF), GHG emissions assessed using the GWP100 climate metric (AR5), have decreased from 124.7 to 44.4 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 5). Under a business-as-usual scenario, GHG emissions are projected to increase and reach 55.2 Mt CO_2e in 2030. This is a consequence of an increase in the size of the herd described in Table 1.

However, with the adoption of GHG mitigation actions, the GHG footprint of the beef cattle sector has the potential to be reduced to 17.6 Mt CO_2e in 2030, a reduction of around 68% compared to business as usual (Fig. 5).

Regarding the projected GHG emissions reduction achieved in 2030 through climate action, the highest contribution came from vegetation management (> 80%; Table 7).

In summary, the achievement of GHG neutrality (carbon neutrality) in the beef cattle sector (including feedlots and LULUCF) will require actions exceeding those modelled in this study (Table 2).

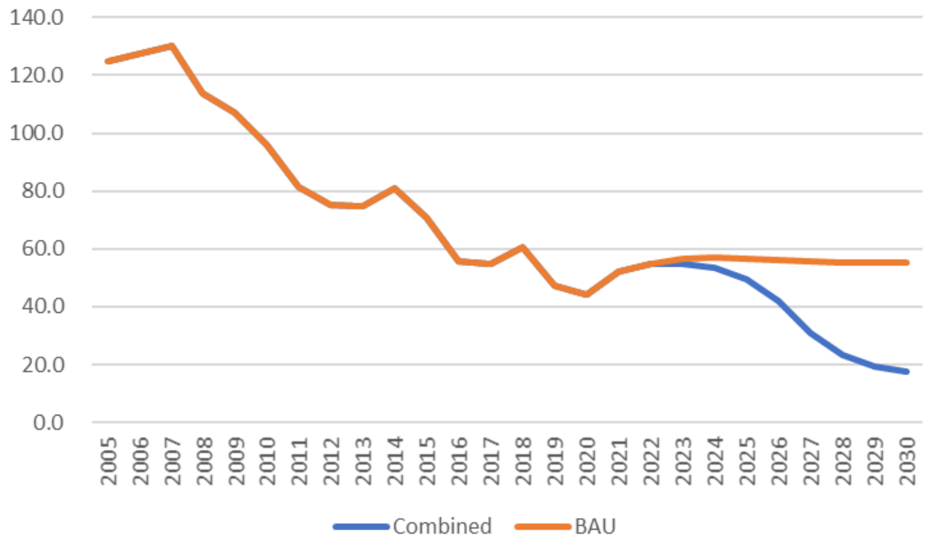

Figure 5. Beef cattle sector (including LULUCF) GHG emissions assessed using the GWP100 climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of a combination of GHG mitigation actions.

Table 7. Contribution to projected GHG emissions reduction in the beef cattle sector (including LULUCF) in 2030. Emissions were assessed using the GWP100 climate metric.

Climate action	**Contribution to GHG emissions reduction %**
Trees on farm	33.2
Savannah burning management	28.5
Soil carbon storage	20.7
Improved herd management	10.9
Feed additives – beef cattle pasture	3.0
Feed additives – beef cattle feedlot	2.5
Forage crops	1.1
Breeding for lower enteric methane emissions	0.1

4.1.6 Red meat industry

Considering the entire Red Meat Industry (including goats and processing), GHG emissions assessed using the GWP100 climate metric (AR5), have decreased from 145.8 to 51.3 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 6). Under a business-as-usual scenario, GHG emissions are projected to increase and reach 63.5 Mt CO_2e in 2030. This is a consequence of an increase in livestock numbers described in Table 1.

However, with the adoption of GHG mitigation actions, the GHG footprint of the Red Meat Industry has the potential to be reduced to 17.3 Mt CO_2e in 2030, a reduction of around 73% compared to business as usual (Fig. 6).

Regarding the projected GHG emissions reduction achieved in 2030 through climate action, the highest contribution came from vegetation management (> 84%; Table 8).

In summary, the achievement of GHG neutrality (carbon neutrality) in the Red Meat Industry (including goats and processing) will require actions exceeding those modelled in this study (Table 2).

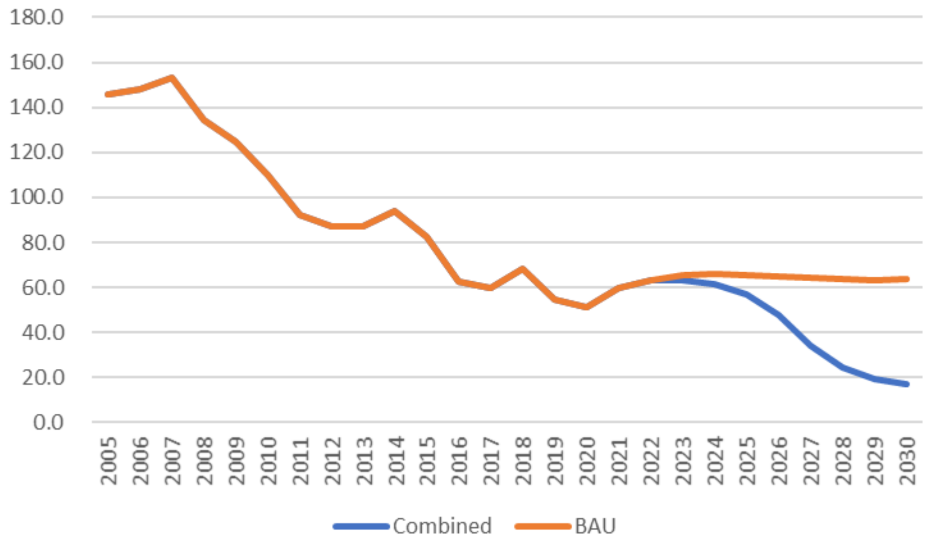

Figure 6. Red Meat Industry (including processing) GHG emissions assessed using the GWP100 climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of a combination of GHG mitigation actions.

Table 8. Contribution to projected GHG emissions reduction in the Red Meat Industry (including processing) in 2030. Emissions were assessed using the GWP100 climate metric.

Climate action	Contribution to GHG emissions reduction %
Trees on farm	44.0
Savannah burning management	23.2
Soil carbon storage	16.9
Improved herd management	8.9
Feed additives – beef cattle pasture	2.4
Feed additives – beef cattle feedlot	2.0
Improved flock management	1.0
Forage crops	0.9
Feed additives – sheep pasture	0.7
Breeding for lower enteric methane emissions	<0.1

4.2 Radiative forcing (RF) footprint

4.2.1 Feedlot sector

Considering only the feedlot sector, the RF footprint has increased from 0.09 to 0.16 mW/m^2 from the reference year of 2005 until 2020 (Fig. 7). Under a business-as-usual scenario, the RF footprint is projected to continue increasing and reach 0.22 mW/m^2 in 2030. This is a consequence of the increase in cattle in feedlots described in Table 1.

However, with the adoption of high impact feed additives in feedlots, the RF footprint of the feedlot sector has the potential to stabilize, reaching a maximum of 0.20 mW/m^2 in 2028 and declining marginally thereafter (Fig. 8).

In summary, the achievement of climate neutrality (i.e., no further contribution to radiative forcing) appears feasible before 2030 based on the use of high impact feed additives, as described in Table 2.

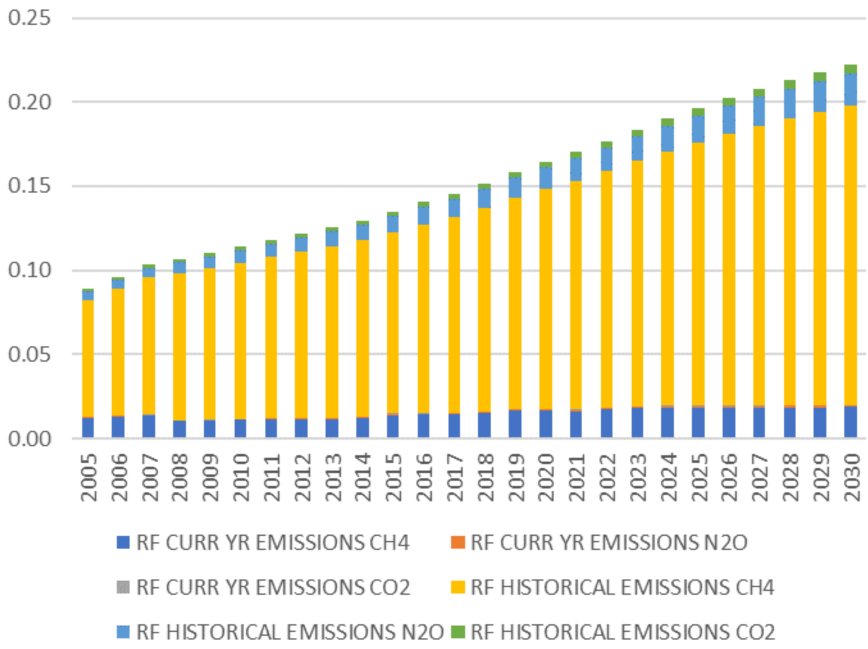

Figure 7. Feedlot sector GHG emissions assessed using the RF footprint (mW/m^2) under a business-as-usual (BAU) scenario. Historical data from 2005 to 2020 and projected data from 2021 onwards.

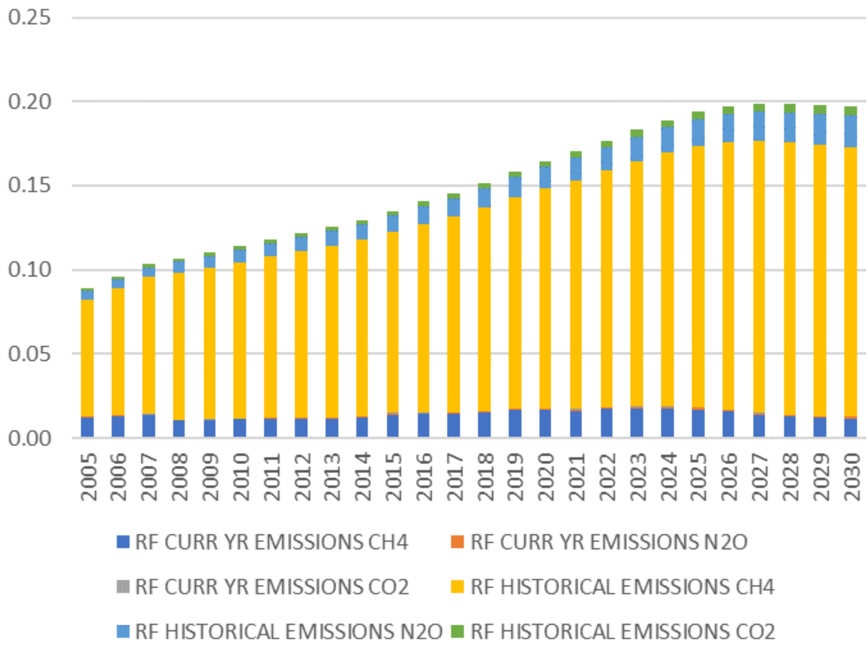

Figure 8. Feedlot sector GHG emissions assessed using the RF footprint (mW/m^2). Historical data from 2005 to 2020 and projected data from 2021 onwards with adoption of high impact feed additives.

4.2.2 Sheep for meat (excluding LULUCF)

Considering the sheep for meat sector (excluding LULUCF), the RF footprint has increased from 0.81 to 0.88 mW/m^2 from the reference year of 2005 until 2020 (Fig. 9). Under a business-as-usual scenario, the RF footprint is projected to continue increasing and reach 0.98 mW/m^2 in 2030. This is a consequence of an increase in the size of the flock described in Table 1.

However, with the adoption of GHG mitigation actions, the RF footprint of the sheep for meat sector (excluding LULUCF) has the potential to be reduced marginally to 0.96 mW/m^2 in 2030 and become very close to plateauing with an annual increase in RF in 2030 of only 0.0013 mW/m^2 as shown in Fig. 10.

Regarding the projected RF footprint reduction achieved in 2030, the highest contribution came from improved flock management (Table 9).

In summary, with the climate actions described in Table 2, the sheep for meat sector (excluding LULUCF) is projected to approach, but not completely achieve, climate neutrality (i.e., no further contribution to radiative forcing). The annual increment to RF is decreased from 0.0223 mW/m^2 in 2005 to 0.0013 mW/m^2 in 2030, representing an almost 95% reduction.

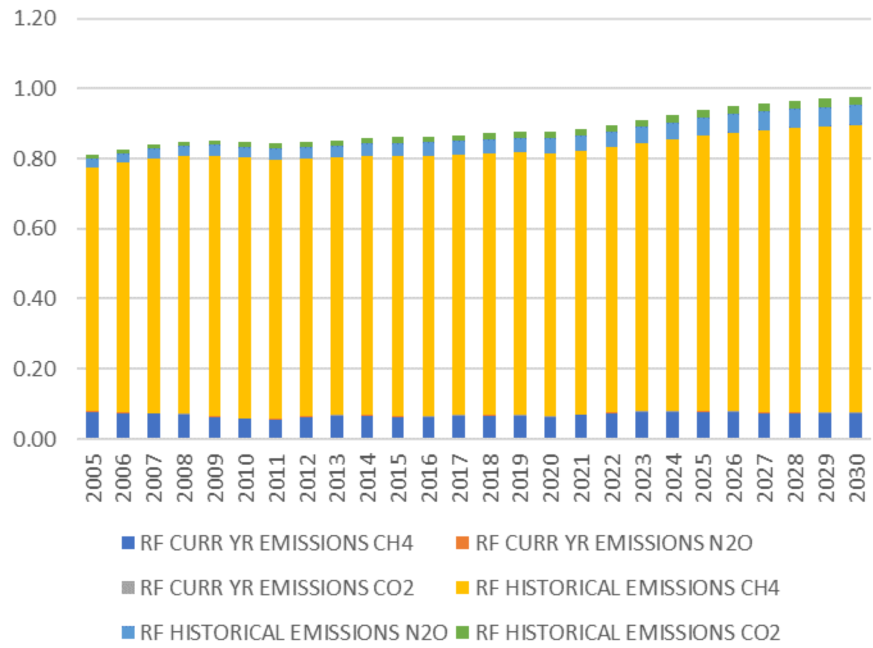

Figure 9. Sheep for meat sector (excluding LULUCF) GHG emissions assessed using the RF footprint (mW/m^2) under a business-as-usual (BAU) scenario. Historical data from 2005 to 2020 and projected data from 2021 onwards.

Table 9. Contribution to projected RF footprint reduction in the sheep for meat sector (excluding LULUCF) in 2030.

Climate action	Contribution to RF footprint reduction %
Improved flock management	56.5
Feed additives – sheep pasture	42.8
Breeding for lower enteric methane emissions	0.7

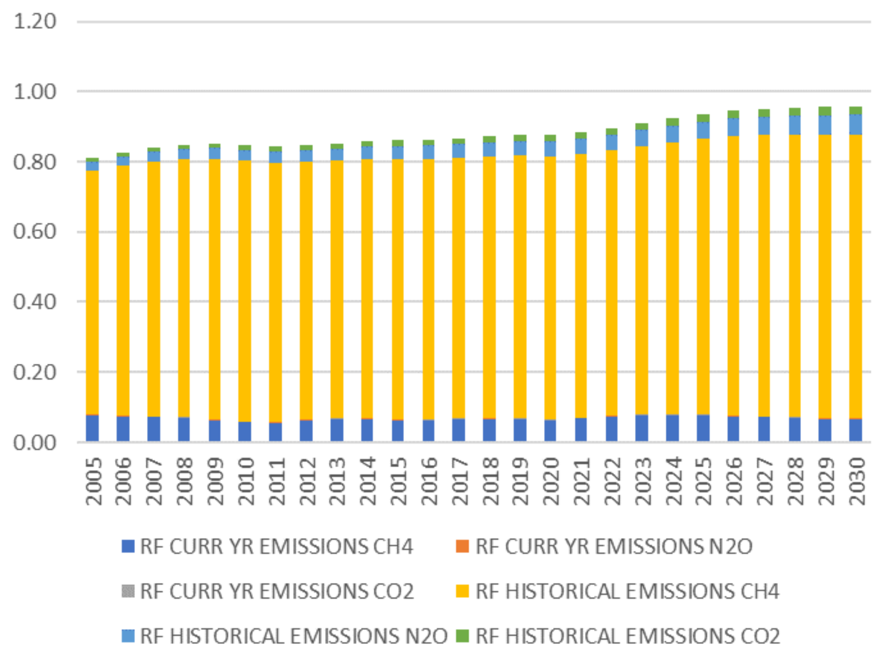

Figure 10. Sheep for meat sector (excluding LULUCF) GHG emissions assessed using the RF footprint (mW/m^2). Historical data from 2005 to 2020 and projected data from 2021 onwards with adoption of a combination of GHG mitigation actions.

4.2.3 Pasture-based beef cattle (excluding LULUCF)

Considering pasture-based beef cattle (excluding LULUCF), the RF footprint has increased from 2.66 to 3.48 mW/m^2 from the reference year of 2005 until 2020 (Fig. 11). Under a business-as-usual scenario, the RF footprint is projected to continue increasing and reach 3.74 mW/m^2 in 2030. This is a consequence of an increase in the size of the herd described in Table 1.

However, with the adoption of GHG mitigation actions, the RF footprint of the pasture-based beef cattle sector (excluding LULUCF) has the potential to stabilize in 2027 and decline back to a level of 3.59 mW/m^2 in 2030 (Fig. 12).

Regarding the projected RF footprint reduction achieved in 2030, the highest contribution came from improved herd management (Table 10).

In summary, the achievement of climate neutrality (i.e., no further contribution to radiative forcing) appears feasible before 2030 based on the climate actions described in Table 2.

Table 10. Contribution to projected RF footprint reduction in the beef cattle sector (excluding LULUCF) in 2030.

Climate action	Contribution to RF footprint reduction %
Improved herd management	70.6
Feed additives – beef cattle pasture	22.0
Forage crops	7.0
Breeding for lower enteric methane emissions	0.4

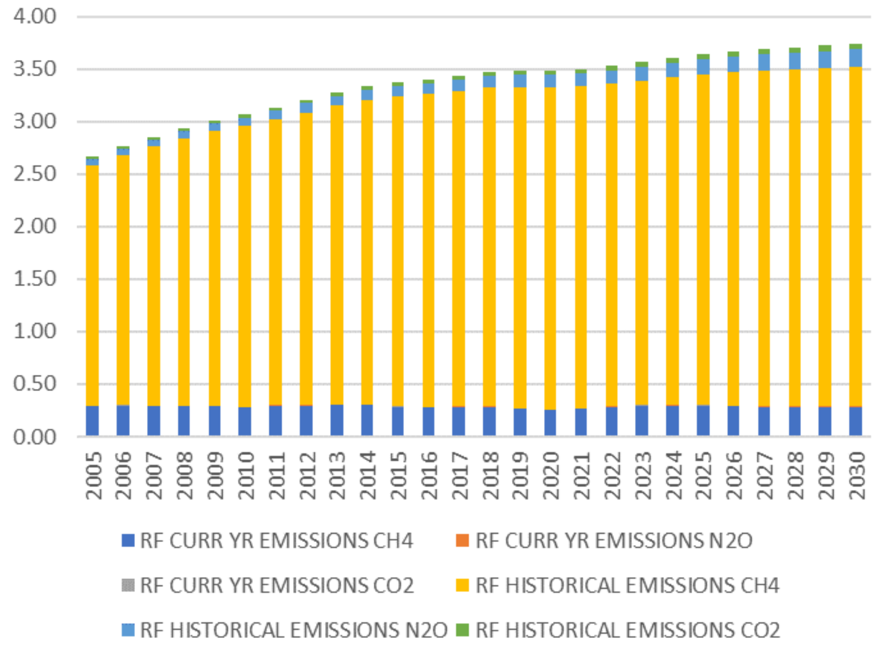

Figure 11. Pasture-based beef cattle (excluding LULUCF) GHG emissions assessed using the RF footprint (mW/m²) under a business-as-usual (BAU) scenario. Historical data from 2005 to 2020 and projected data from 2021 onwards.

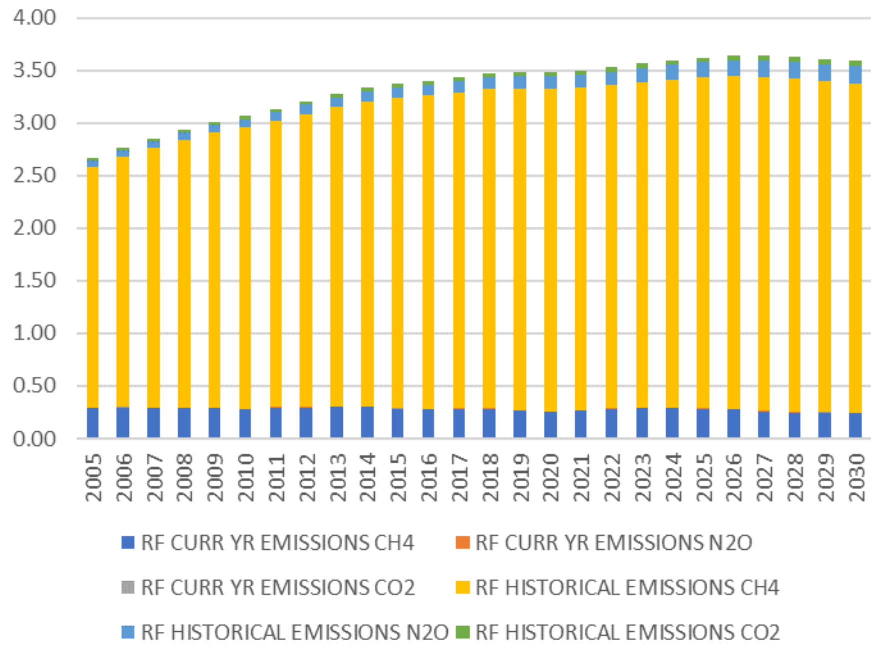

Figure 12. Pasture-based beef cattle (excluding LULUCF) GHG emissions assessed using the RF footprint (mW/m²). Historical data from 2005 to 2020 and projected data from 2021 onwards with adoption of a combination of GHG mitigation actions.

4.2.4 Sheep for meat (including LULUCF)

Considering the sheep for meat sector (including LULUCF), the RF footprint has increased from 1.03 to 1.07 mW/m^2 from the reference year of 2005 until 2020 (Fig. 13). Under a business-as-usual scenario, the RF footprint is projected to plateau in 2027 and decline marginally thereafter to the level of 1.09 mW/m^2 in 2030.

However, with the adoption of GHG mitigation actions, the RF footprint of the sheep for meat sector (including LULUCF) has the potential to plateau earlier, in 2026, declining thereafter to the level of 1.02 mW/m^2 in 2030 (Fig. 14).

Regarding the projected RF footprint reduction achieved in 2030, the highest contribution came from trees on farm (Table 11).

In summary, the achievement of climate neutrality (i.e., no further contribution to radiative forcing) appears feasible before 2030 based on the combination of climate actions described in Table 2.

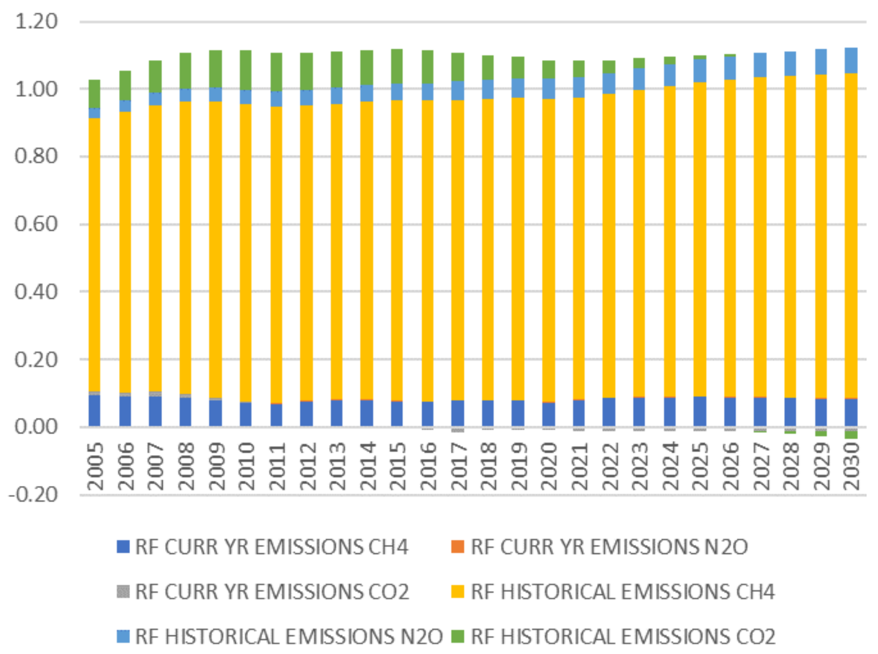

Figure 13. Sheep for meat sector (including LULUCF) GHG emissions assessed using the RF footprint (mW/m^2) under a business-as-usual (BAU) scenario. Historical data from 2005 to 2020 and projected data from 2021 onwards.

Table 11. Contribution to projected RF footprint reduction in the sheep for meat sector (including LULUCF) in 2030.

Climate action	Contribution to RF footprint reduction %
Trees on farm	71.2
Improved flock management	16.3
Feed additives – sheep pasture	12.3
Breeding for lower enteric methane emissions	0.2

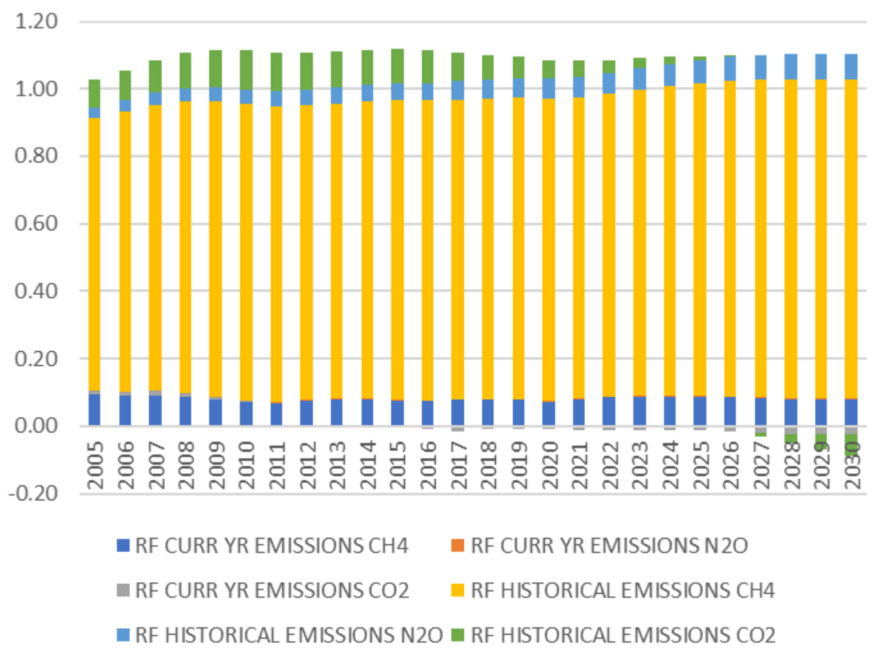

Figure 14. Sheep for meat sector (including LULUCF) GHG emissions assessed using the RF footprint (mW/m^2). Historical data from 2005 to 2020 and projected data from 2021 onwards with adoption of a combination of GHG mitigation actions.

4.2.5 Beef cattle (including feedlots and LULUCF)

Considering the beef cattle sector (including LULUCF), the RF footprint has increased from 4.65 to 5.94 mW/m^2 from the reference year of 2005 until 2020 (Fig. 15). Under a business-as-usual scenario, the RF footprint is projected to almost plateau but reach 6.11 mW/m^2 in 2030.

However, with the adoption of GHG mitigation actions, the RF footprint of the beef cattle sector (including LULUCF) has the potential to plateau in 2026, declining thereafter to the level of 5.73 mW/m^2 in 2030 (Fig. 16).

Regarding the projected RF footprint reduction achieved in 2030, the highest contribution came from improved herd management (Table 12).

In summary, the achievement of climate neutrality (i.e., no further contribution to radiative forcing) appears feasible before 2030 based on the combination of climate actions described in Table 2.

Table 12. Contribution to projected RF footprint reduction in the beef cattle sector (including LULUCF) in 2030.

Climate action	Contribution to RF footprint reduction %
Improved herd management	28.2
Trees on farm	21.7
Savannah burning management	18.5
Soil carbon storage	13.5
Feed additives – beef cattle pasture	8.8
Feed additives – beef cattle feedlot	6.4
Forage crops	2.8
Breeding for lower enteric methane emissions	0.1

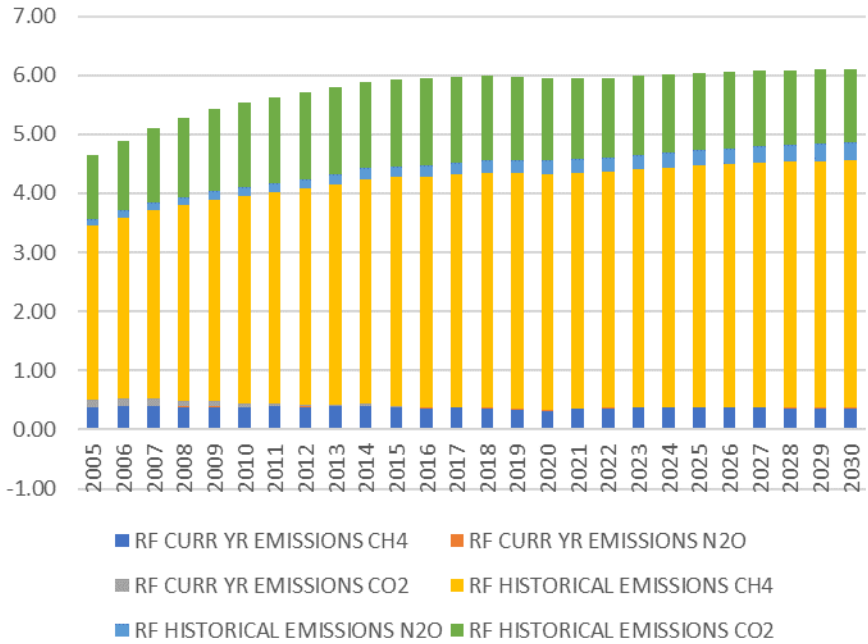

Figure 15. Beef cattle sector (including LULUCF) GHG emissions assessed using the RF footprint (mW/m^2) under a business-as-usual (BAU) scenario. Historical data from 2005 to 2020 and projected data from 2021 onwards.

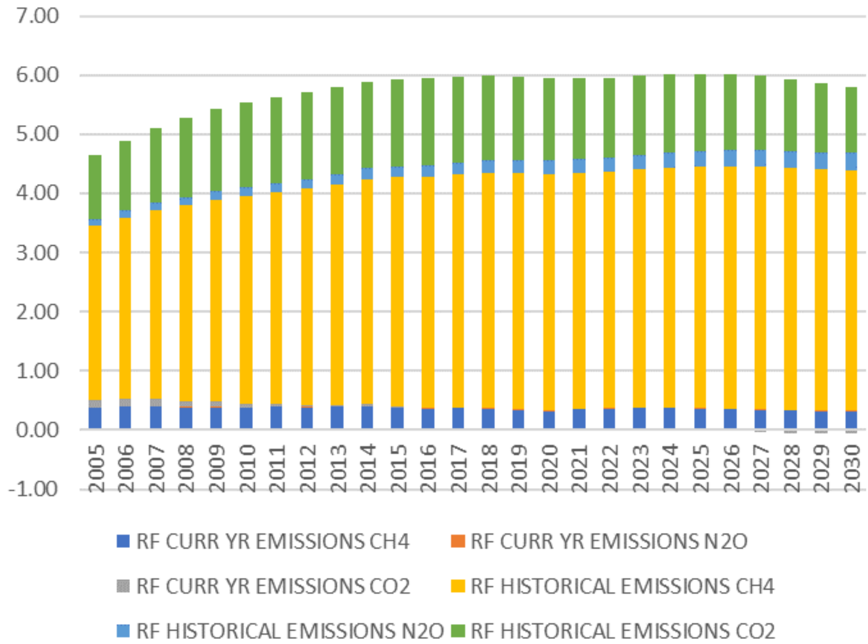

Figure 16. Beef cattle sector (including LULUCF) GHG emissions assessed using the RF footprint (mW/m^2). Historical data from 2005 to 2020 and projected data from 2021 onwards with adoption of a combination of GHG mitigation actions.

4.2.6 Red meat industry

Considering the Red Meat Industry (including goats and processing), the RF footprint has increased from 5.71 to 7.07 mW/m^2 from the reference year of 2005 until 2020 (Fig. 17). Under a business-as-usual scenario, the RF footprint is projected to almost plateau but reach 7.26 mW/m^2 in 2030.

However, with the adoption of GHG mitigation actions, the RF footprint of the Red Meat Industry (including goats and processing) has the potential to plateau in 2026, declining thereafter to the level of 6.81 mW/m^2 in 2030 (Fig. 18).

Regarding the projected RF footprint reduction achieved in 2030, the highest contribution came from trees on farm, followed by improved herd management (Table 13).

In summary, the achievement of climate neutrality (i.e., no further contribution to radiative forcing) appears feasible before 2030 based on the combination of climate actions described in Table 2.

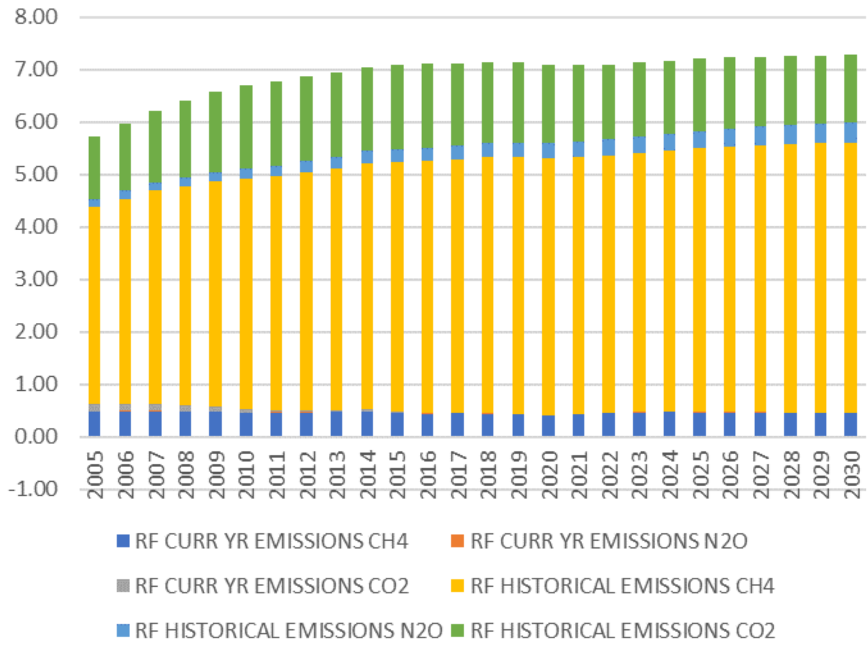

Figure 17. Red Meat Industry (including processing) GHG emissions assessed using the RF footprint (mW/m^2) under a business-as-usual (BAU) scenario. Historical data from 2005 to 2020 and projected data from 2021 onwards.

Table 13. Contribution to projected RF footprint reduction in the Red Meat Industry (including LULUCF) in 2030.

Climate action	Contribution to GHG emissions reduction %
Trees on farm	29.6
Improved herd management	23.7
Savannah burning management	15.6
Soil carbon storage	11.4
Feed additives – beef cattle pasture	7.4
Feed additives – beef cattle feedlot	5.3
Improved flock management	2.6
Forage crops	2.3
Feed additives – sheep pasture	2.0
Breeding for lower enteric methane emissions	0.1

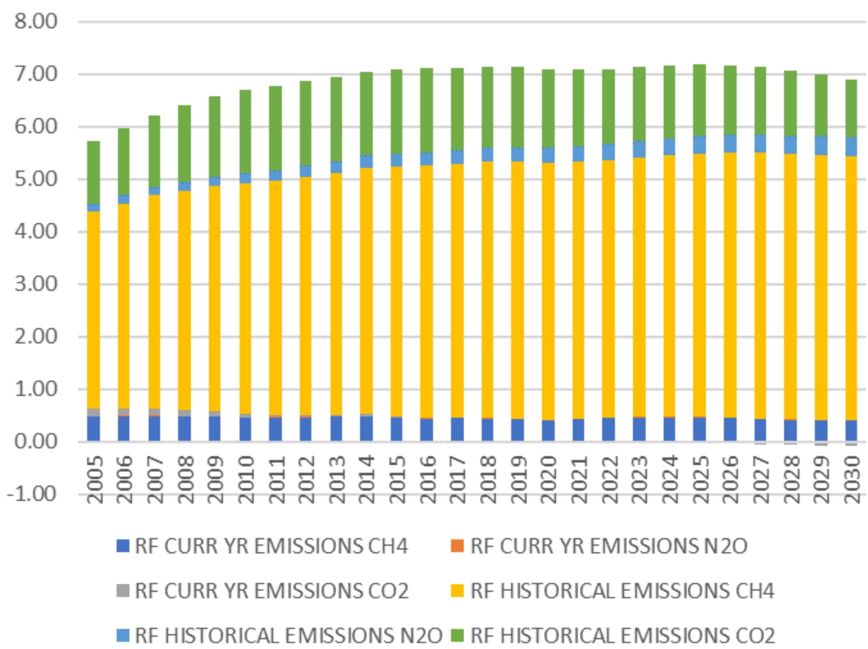

Figure 18. Red Meat Industry (including processing) GHG emissions assessed using the RF footprint (mW/m^2). Historical data from 2005 to 2020 and projected data from 2021 onwards with adoption of a combination of GHG mitigation actions.

4.3 Warming potential (GWP*)

4.3.1 Feedlot sector

Considering only the feedlot sector, GHG emissions assessed using the GWP* climate metric have decreased from 6.25 to 4.55 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 19). Under a business-as-usual scenario, GHG emissions are projected to subsequently increase and reach 5.04 Mt CO_2e in 2030. This is a consequence of the increase in cattle in feedlots described in Table 1.

However, with the adoption of high impact feed additives in feedlots, the GHG footprint of the feedlot sector has the potential to be reduced steeply to -0.44 Mt CO_2e in 2030, achieving climate neutrality in that year (Fig. 19).

In summary, the achievement of climate neutrality (i.e., no net contribution to future warming) appears feasible by 2030 based on the use of high impact feed additives, as described in Table 2.

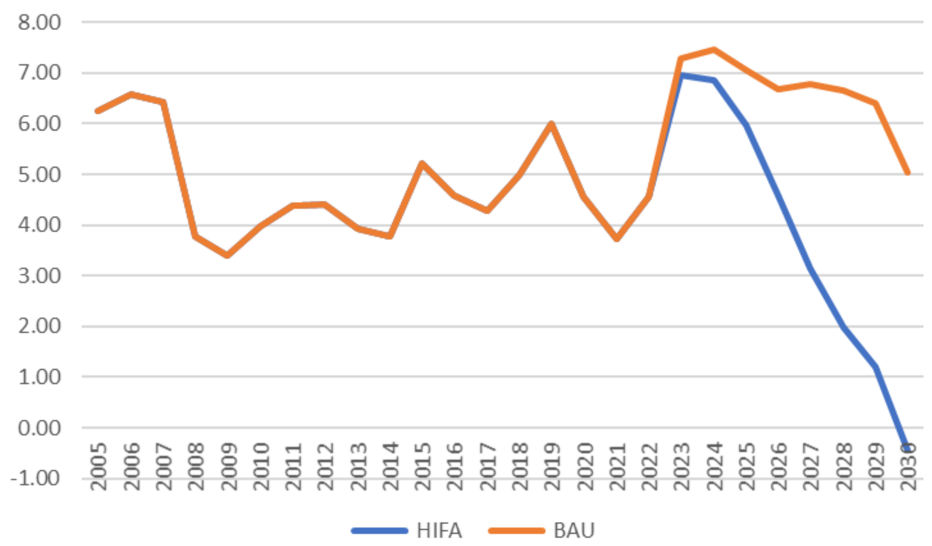

Figure 19. Feedlot sector GHG emissions assessed using the GWP* climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of high impact feed additives (HIFA).

4.3.2 Sheep for meat (excluding LULUCF)

Considering the sheep for meat sector (excluding LULUCF), GHG emissions assessed using the GWP* climate metric have decreased from -3.9 to -8.5 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 20). Under a business-as-usual scenario, GHG emissions are projected to increase and reach 11.7 Mt CO_2e in 2030. This is a consequence of an increase in the size of the flock described in Table 1. The GWP* climate metric is especially sensitive to increases in the rate of methane emission associated with the projected increase in livestock numbers.

However, with the adoption of GHG mitigation actions, the GHG footprint of the sheep meat sector (excluding LULUCF) has the potential to be reduced to 7.2 Mt CO_2e in 2030, a level higher than in 2020, but around 39% below the projected business-as-usual level in 2030 (Fig. 20).

Regarding the projected GHG emissions reduction achieved in 2030 through climate action, the highest contribution came from improved flock management (Table 14).

In summary, the achievement of climate neutrality (i.e., no net contribution to future warming) in the sheep for meat sector (excluding LULUCF) will require actions exceeding those modelled in this study (Table 2).

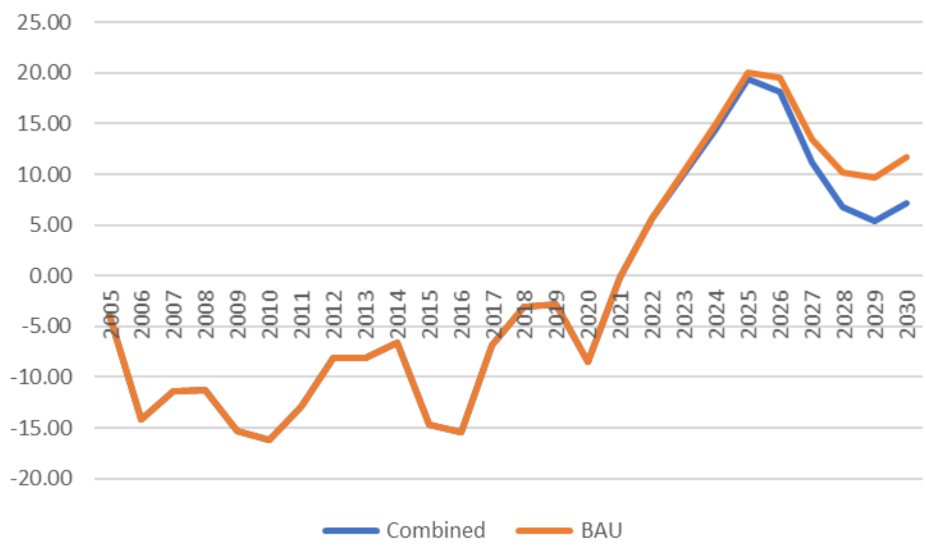

Figure 20. Sheep for meat sector (excluding LULUCF) GHG emissions assessed using the GWP* climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of a combination of GHG mitigation actions.

Table 14. Contribution to projected GHG emissions reduction in the sheep for meat sector (excluding LULUCF) in 2030. Emissions were assessed using the GWP* climate metric.

Climate action	Contribution to GHG emissions reduction %
Improved flock management	59.8
Feed additives – sheep pasture	39.5
Breeding for lower enteric methane emissions	0.7

4.3.3 Pasture-based beef cattle (excluding LULUCF)

Considering the pasture-based beef cattle sector (excluding LULUCF and feedlots), GHG emissions assessed using the GWP* climate metric have decreased from 37.9 to -14.0 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 21). Under a business-as-usual scenario, GHG emissions are projected to increase and reach 18.2 Mt CO_2e in 2030. This is a consequence of an increase in the size of the herd described in Table 1. The GWP* climate metric is especially sensitive to increases in the rate of methane emission associated with the projected increase in livestock numbers.

However, with the adoption of GHG mitigation actions, the GHG footprint of the pasture-based beef cattle sector has the potential to be steeply reduced, achieving climate neutrality in 2026 and the level -15.4 Mt CO_2e in 2030 (Fig. 21).

Regarding the projected GHG emissions reduction achieved in 2030 through climate action, the highest contribution came from improved herd management (Table 15).

In summary, the achievement of climate neutrality (i.e., no net contribution to future warming) appears feasible before 2030 based on the combination of climate actions described in Table 2.

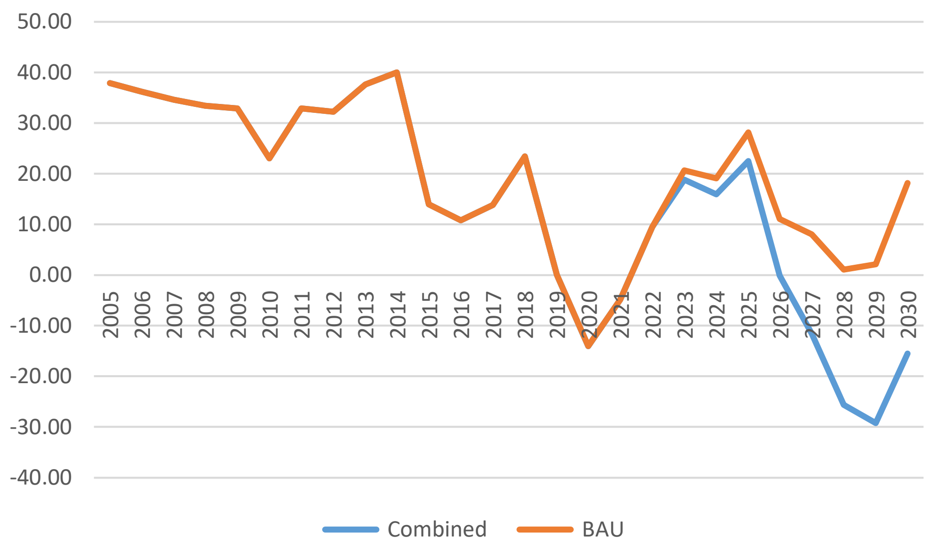

Figure 21. Beef cattle sector (excluding LULUCF) GHG emissions assessed using the GWP* climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of a combination of GHG mitigation actions.

Table 15. Contribution to projected GHG emissions reduction in the beef cattle sector (excluding LULUCF) in 2030. Emissions were assessed using the GWP* climate metric.

Climate action	Contribution to GHG emissions reduction %
Improved herd management	72.5
Feed additives – beef cattle pasture	19.9
Forage crops	7.2
Breeding for lower enteric methane emissions	0.4

4.3.4 Sheep for meat (including LULUCF)

Considering the sheep for meat sector (including LULUCF), GHG emissions assessed using the GWP* climate metric have decreased from 1.8 to -16.1 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 22), largely due to declining flock numbers. Under a business-as-usual scenario, GHG emissions are projected to increase and reach 4.5 Mt CO_2e in 2030. This is a consequence of an increase in the size of the flock described in Table 1. The GWP* climate metric is especially sensitive to increases in the rate of methane emission associated with the projected increase in livestock numbers.

However, with the adoption of GHG mitigation actions, the GHG footprint of the sheep meat sector (including LULUCF) has the potential to be reduced to -7.9 Mt CO_2e in 2030, achieving climate neutrality in 2027 (Fig. 22).

Regarding the projected GHG emissions reduction achieved in 2030 through climate action, the majority was attributable to planting trees on farms (> 60%; Table 16).

In summary, the achievement of climate neutrality (i.e., no net contribution to future warming) appears feasible before 2030 based on the combination of climate actions described in Table 2.

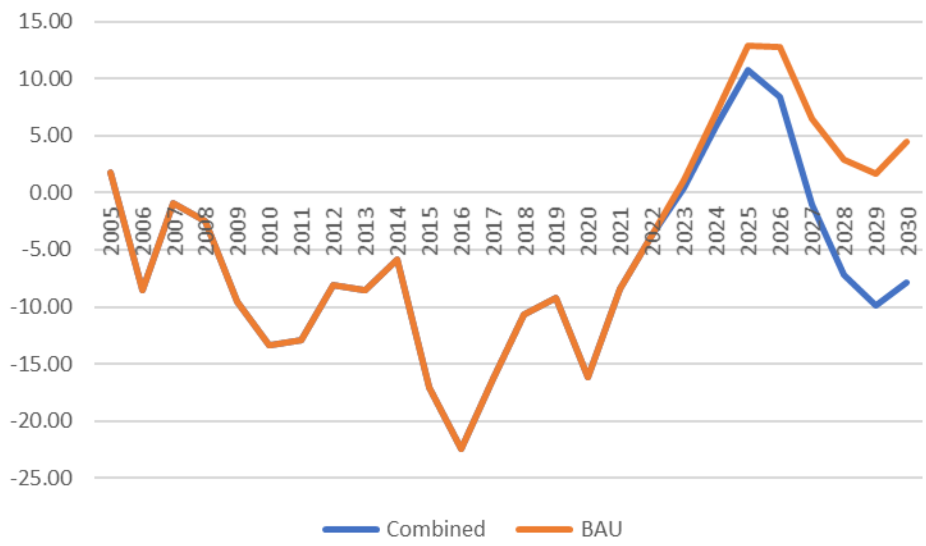

Figure 22. Sheep for meat sector (including LULUCF) GHG emissions assessed using the GWP* climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of a combination of GHG mitigation actions.

Table 16. Contribution to projected GHG emissions reduction in the sheep for meat sector (including LULUCF) in 2030. Emissions were assessed using the GWP* climate metric.

Climate action	Contribution to GHG emissions reduction %
Trees on farm	63.3
Improved flock management	22.0
Feed additives – sheep pasture	14.5
Breeding for lower enteric methane emissions	0.3

4.3.5 Beef cattle (including feedlots and LULUCF)

Considering the beef cattle sector (including feedlots and LULUCF), GHG emissions assessed using the GWP* climate metric have decreased from 124.7 to -28.4 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 23). Under a business-as-usual scenario, GHG emissions are projected to increase and reach 16.2 Mt CO_2e in 2030. This is a consequence of an increase in the size of the herd described in Table 1. The GWP* climate metric is especially sensitive to increases in the rate of methane emission associated with the projected increase in livestock numbers.

However, with the adoption of GHG mitigation actions, the GHG footprint of the beef cattle sector has the potential to be reduced to -53.9 Mt CO_2e in 2030, achieving climate neutrality in 2026 (Fig. 23).

Regarding the projected GHG emissions reduction achieved in 2030 through climate action, the highest contribution came from improved herd management (Table 17).

In summary, the achievement of climate neutrality (i.e., no net contribution to future warming) appears feasible before 2030 based on the combination of climate actions described in Table 2.

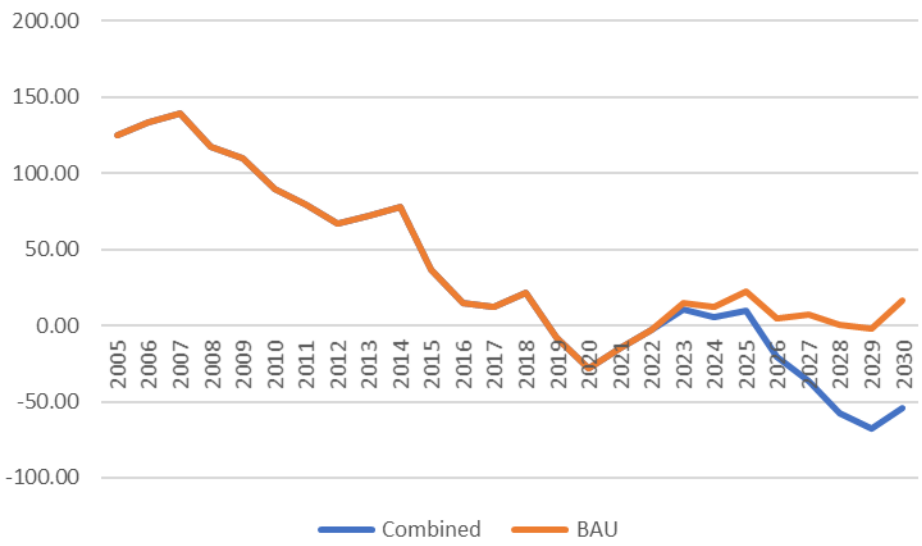

Figure 23. Beef cattle sector (including LULUCF) GHG emissions assessed using the GWP* climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of a combination of GHG mitigation actions.

Table 17. Contribution to projected GHG emissions reduction in the beef cattle sector (including LULUCF) in 2030. Emissions were assessed using the GWP* climate metric.

Climate action	Contribution to GHG emissions reduction %
Improved herd management	34.8
Trees on farm	17.8
Savannah burning management	15.3
Soil carbon storage	11.1
Feed additives – beef cattle pasture	9.6
Feed additives – beef cattle feedlot	7.8
Forage crops	3.5
Breeding for lower enteric methane emissions	0.2

4.3.6 Red meat industry

Considering the entire Red Meat Industry (including goats and processing), GHG emissions assessed using the GWP* climate metric have decreased from 127.8 to -43.4 Mt CO_2e from the reference year of 2005 until 2020 (Fig. 24). Under a business-as-usual scenario, GHG emissions are projected to increase and reach 22.0 Mt CO_2e in 2030. This is a consequence of an increase in livestock numbers described in Table 1.

However, with the adoption of GHG mitigation actions, the GHG footprint of the Red Meat Industry has the potential to be reduced to -60.6 Mt CO_2e in 2030, achieving climate neutrality in 2026 (Fig. 24).

Regarding the projected GHG emissions reduction achieved in 2030 through climate action, the highest contribution came from improved herd management as well as vegetation management (Table 18).

In summary, the achievement of climate neutrality (i.e., no net contribution to future warming) appears feasible before 2030 based on the combination of climate actions described in Table 2.

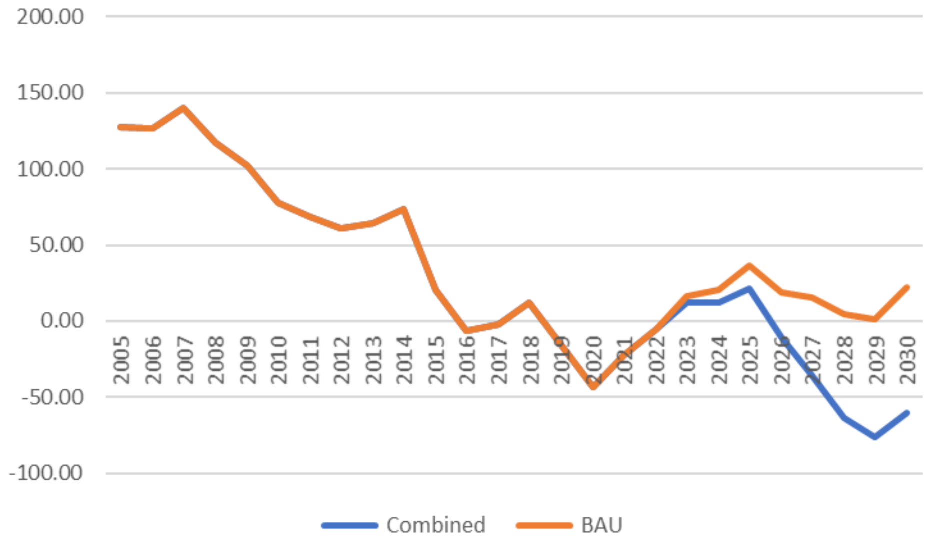

Figure 24. Red Meat Industry (including processing) GHG emissions assessed using the GWP* climate metric (Mt CO_2e). Historical data from 2005 to 2020 and projected data from 2021 onwards under a business-as-usual (BAU) scenario and with adoption of a combination of GHG mitigation actions.

Table 18. Contribution to projected GHG emissions reduction in the Red Meat Industry (including processing) in 2030. Emissions were assessed using the GWP* climate metric.

Climate action	Contribution to GHG emissions reduction %
Improved herd management	29.5
Trees on farm	24.7
Savannah burning management	13.0
Soil carbon storage	9.4
Feed additives – beef cattle pasture	8.1
Feed additives – beef cattle feedlot	6.6
Improved flock management	3.3
Forage crops	3.0
Feed additives – sheep pasture	2.2
Breeding for lower enteric methane emissions	0.2

4.4 Trajectory of methane emissions

The Global Methane Pledge is a commitment to voluntary actions that contribute to reducing global methane emissions by at least 30% from 2020 levels by 2030 (Climate & Clean Air Coalition 2022).

As shown in Table 19, under a business-as-usual scenario, methane emissions in the Australian Red Meat Industry are projected to increase by 13.8% from 2020 to 2030. Furthermore, methane emissions are projected to increase in all sectors of the industry: feedlot, beef cattle, and sheep for meat.

However, with the combination of GHG mitigation and sequestration interventions outlined in this report (Table 2), methane emissions have the potential to be decreased by 0.2% from 2020 to 2030 (Table 20).

Table 19. Projected change in methane emissions from 2020 to 2030 under business-as-usual.

Year	2020 kt	2030 kt	Change %
Feedlot sector	79	89	12.5
Sheep for meat (excluding LULUCF)	293	345	17.8
Pasture-based beef cattle (excluding LULUCF)	1189	1339	12.6
Sheep for meat (including LULUCF)	343	400	16.6
Beef cattle (including feedlots and LULUCF)	1527	1729	13.2
Red Meat Industry	1873	2132	13.8

Table 20. Projected change in methane emissions from 2020 to 2030 with adoption of a combination of GHG mitigation actions.

Year	2020 kt	2030 kt	Change %
Feedlot sector	79	56	-29.3
Sheep for meat (excluding LULUCF)	293	317	8.4
Pasture-based beef cattle (excluding LULUCF)	1189	1137	-4.4
Sheep for meat (including LULUCF)	343	373	8.6
Beef cattle (including feedlots and LULUCF)	1527	1493	-2.2
Red Meat Industry	1873	1869	-0.2

5. Conclusion

5.1 Red meat industry projected GHG footprint

With a business-as-usual scenario, the GHG footprint (GWP100) of the Australian Red Meat Industry is projected to increase from 51.3 Mt CO_2e in 2020 to 63.5 Mt CO_2e in 2030. This is essentially the consequence of an anticipated increase in livestock numbers over this period.

However, with the combination of GHG mitigation and sequestration interventions modelled, the GHG footprint has the potential to decrease to 17.3 Mt CO_2e in 2030. Additional vegetation management, i.e., tree planting on farms, soil carbon sequestration on farms, and savannah burning management, account for most of the reduction.

While this represents a substantial net GHG emissions reduction compared to 2005, the achievement of the CN30 target requires actions exceeding those modelled in this study.

5.2 Climate neutral pathway

With a business-as-usual scenario, the Australian Red Meat Industry is projected to almost reach climate neutrality (i.e., no further contribution to radiative forcing) by 2030, with the annual increase in radiative forcing decreasing by 96% compared to the 2005 level.

However, with the combination of GHG mitigation and sequestration interventions modelled, the industry is projected to achieve climate neutrality in 2026.

The pasture-based beef cattle and sheep for meat sectors are both projected to individually achieve climate neutrality in 2026. The feedlot sector is projected to achieve climate neutrality two years later in 2028.

With the pathway to climate neutrality, additional vegetation management, i.e., tree planting on farms, soil carbon sequestration on farms, and savannah burning management, account for approximately half of the reduction.

In summary, climate neutrality appears to be realistically achievable, with scope for industry growth, and without excessive reliance on vegetation management.

5.3 Climate neutral as an industry target

There is increasing acknowledgement by the IPCC that the goals for short-lived GHGs are different from the goals for long-lived GHGs (IPCC 2021):

> *"Stabilizing the climate will require strong, rapid, and sustained reductions in greenhouse gas emissions, and reaching net zero CO_2 emissions. Limiting other greenhouse gases and air pollutants, especially methane, could have benefits both for health and the climate."* [Emphasis added]

Therefore, Climate Neutral should not be considered as a lesser target compared to Carbon Neutral or GHG Neutral based on the GWP100 climate metric. The RF footprint is based on IPCC science and is arguably more transparently aligned with the climate stabilization goal of the Paris Agreement.

Indeed, there may be reason to reconsider the industry's current use of the GWP100 climate metric for GHG emissions reporting and target setting, as ongoing use of this metric by the industry affirms its applicability as a relevant measure of climate impact by the industry.

It is also important to note that pursuing an industry Climate Neutral target does not interfere with individual producers or processors participating in GWP100-based reporting frameworks or labelling programmes should they choose to do so.

However, the adoption of Climate Neutrality as a standard by the industry would provide greater scope for producers to monetarise their GHG mitigation and sequestration actions rather than relying on these interventions to offset the biogenic methane emissions from livestock.

Importantly, the adoption of Climate Neutrality as a standard by the industry would provide greater scope for the industry to grow and contribute to global food supplies.

6. Future research and recommendations

For an industry with substantial biogenic methane emissions, a net zero GHG emission target exceeds the climate stabilization goal of the Paris Agreement with potentially large economic and social cost.

Recommendation 1: The Australian Red Meat Industry should formally adopt a Climate Neutral target and reconsider the ongoing CN30 target.

Most of the GHG mitigation and sequestration interventions modelled in this study will not be identified by the current National Greenhouse Gas Inventory processes.

Recommendation 2: New inventory methods will need to be developed. For example, to recognise the GHG emissions benefits of high impact feed additives incorporated into the diets of cattle in feedlots, it will be necessary to 1) collect data on the number of cattle receiving the additive, and 2) develop and apply new models for methane emissions applicable to these cattle.

"Climate Neutrality" is an emerging concept that would benefit from formalisation of terminology and methods.

Recommendation 3: MLA should establish a project to formalise terminology and methods related to Climate Neutrality in the national and international contexts. In the national context, this would involve coordination with other industries with substantial biogenic emissions (e.g., Dairy, Wool). In addition, MLA should become involved in the development of the common approach to GHG accounting across agricultural sectors in Australia and take action to ensure the Climate Neutral approach is facilitated. In the international context, coordination could be undertaken with international organisations such as IMS, IDF and FAO, as well as other national organisations directly.

There are certain arguments against the Climate Neutral approach, based primarily on fairness, i.e., that the approach favours countries that established their herds long ago and unfairly constrains expansion of the livestock industries in some developing countries.

Recommendation 4: MLA should support the development of an academic paper that evaluates various RF stabilization targets for the livestock industries in the context of the Paris Agreement climate stabilisation goal.

The Climate Neutral approach has been applied at the industry scale, where longer term change in the rate of methane emissions can be readily assessed. It is not immediately clear how the approach should be operationalised at the scale of individual producers/processors, and for products.

Recommendation 5: MLA should support a scoping assessment on application of Climate Neutrality to individual enterprises and to products.

7. References

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 of CO_2-equivalent emissions of short-lived climate pollutants under ambitious mitigation Clim. Atmos. Sci. 1, 16, doi.org/10.1038/s41612-018-0026-8.

ALLEN, M., LYNCH, J., CAIN, M., FRAME, D. 2022. Climate Metrics for Ruminant Livestock. Oxford, UK: Oxford Martin Programme on Climate Pollutants.

ALMEIDA, A.K., HEGARTY, R.S., COWIE, A. 2021. Meta-analysis quantifying the potential of dietary additives and rumen modifiers for methane mitigation in ruminant production systems. Anim. Nutr. 7, 1219-1230.

BLACK, J.L., DAVISON, T.M., BOX, I. 2021. Methane emissions from ruminants in Australia: Mitigation potential and applicability of mitigation strategies. Animals 11, 951.

BROOKE, C.G., ROQUE, B.M., SHAW, C., ET AL. 2020. Methane reduction potential of two Pacific coast macroalgae during in vitro ruminant fermentation. Front. Mar. Sci. 7, 561.

CADY, R.A. 2020. A Literature Review of GWP*: A Proposed Method for Estimating Global Warming Potential (GWP*) of Short-lived Climate Pollutants like Methane. Rosemont, Illinois: Global Dairy Platform.

Climate & Clean Air Coalition. 2022. Global Methane Pledge. Homepage | Global Methane Pledge (Accessed 18 November 2022).

DISER. 2022a. National Inventory Report 2020 Volume 1. Canberra: Australian Government Department of Industry, Science, Energy and Resources.

DISER. 2022b. National Inventory Report 2020 Volume 2. Canberra: Australian Government Department of Industry, Science, Energy and Resources.

FAO. 2022. Methane Emissions in Agriculture – sources, quantification, mitigation and metrics. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

FOUTS, J.Q., HONAN, M.C., ROQUE, B.M., TRICARICO, J.M., KEBREAB, E. 2022. Enteric methane mitigation interventions. Transl. Anim. Sci. 6, txac041.

HEGARTY, R.S., PASSETTI, R.A.C., DITTMER, K.M., ET AL. 2021. An Evaluation of Evidence for Efficacy and Applicability of Methane Inhibiting Feed Additives for Livestock. An evaluation of emerging feed additives to reduce methane emissions from livestock (cgiar.org) (Accessed 22 August 2022).

IPCC. 2021. Climate change widespread, rapid, and intensifying – IPCC. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/ (Accessed 9 Nov 2022).

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.

KINLEY, R.D., DE NYS, R., VUCKO, M.J., MACHADO, L., TOMKINS, N.W. 2016. The red macroalgae *Asparagopsis taxiformis* is a potent natural antimethanogenic that reduces methane production during in vitro fermentation with rumen fluid. Anim. Prod. Sci. 56, 282–289.

KINLEY, R.D., MARTINEZ-FERNANDEZ, G., MATTHEWS, M.K., DE NYS, R., MAGNUSSON, M., TOMKINS, N.W. 2020. Mitigating the carbon footprint and improving productivity of ruminant livestock agriculture using a red seaweed. J. Clean. Prod. 259, 120836.

MACHADO, L., MAGNUSSON, M., PAUL, N.A., DE NYS, R., TOMKINS N. 2014. Effects of marine and freshwater macroalgae on in vitro total gas and methane production. PLoS One 9, e85289.

MAYBERRY, D. 2022. Greenhouse Gas Footprint of the Australian Red Meat Production and Processing Sectors 2019. North Sydney: Meat & Livestock Australia Limited.

MLA. 2021a. Carbon storage. Carbon storage | Meat & Livestock Australia (mla.com.au) (Accessed 1 September 2022).

MLA. 2021b. Industry GHG emissions avoidance. Industry GHG emissions avoidance | Meat & Livestock Australia (mla.com.au) (Accessed 1 September 2022).

MLA. 2022a. Industry projections 2022 – Australian cattle – June update. North Sydney: Meat & Livestock Australia Limited.

MLA. 2022b. Industry projections 2022 – Australian sheep – July update. North Sydney: Meat & Livestock Australia Limited.

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.

PLACE, S.E., MITLOEHNER, F.M. 2021. Pathway to Climate Neutrality for U.S. Beef and Dairy Cattle Production. Davis: University of California.

RIDOUTT, B. 2021a. Climate impact of Australian livestock production assessed using the GWP* climate metric. Liv. Sci. 246, 104459.

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

RIDOUTT, B. 2022. Greenhouse Gas Footprint of the Australian Red Meat Production and Processing Sectors 2020. North Sydney: Meat & Livestock Australia Limited.

RIDOUTT, B., LEHNERT, S.A., DENMAN, S., CHARMLEY, E., KINLEY, R., DOMINIK, S. 2022. Potential GHG emission benefits of *Asparagopsis taxiformis* feed supplement in Australian beef cattle feedlots. J. Clean. Prod. 337, 130499.

RIDOUTT, B., MAYBERRY D. 2021. Assessment of Climate Accounting Metrics for the Australian Red Meat Industry. North Sydney: Meat & Livestock Australia Limited.

ROQUE, B.M., VENEGAS, M., KINLEY, R.D., DE NYS, R., DUARTE, T.L., YANG, X., KEBREAB, E. 2021. Red seaweed (*Asparagopsis taxiformis*) supplementation reduces enteric methane by over 80 percent in beef steers. PLoS One 16 (3), e0247820.

SMITH, M.A., CAIN, M., ALLEN, M.R. 2021. Further improvement of warming-equivalent emissions calculation. Clim. Atmos. Sci. 4, 19, doi.org/10.1038/s41612-021-00169-8.