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An Industry Life Cycle Assessment for Sheep Production in Western Australia

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Integrity Ag & Environment

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List of Abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ADG	average daily gain
AWTA	Australian Wool Testing Authority
CSF	case study farm
CSWB	Central and South Wheat Belt
DAWE	Department of Agriculture, Water and the Environment
DPIRD	Department of Primary Industries and Regional Development
DSE	dry sheep equivalent
HSCW	hot standard carcase weight
FY	financial year
GHG	greenhouse gas
GW	greasy wool
GWP	global warming potential
KRF	Katanning Research Facility
LCA	life cycle assessment
LW	live weight
NEWB	North and East Wheat Belt
NGGI	National Greenhouse Gas Inventory
NIR	National Inventory Report
PIRSA	Department of Primary Industries and Regions
RAF	regional average farm
SGD	Sustainable Development Goals
SWC	South West Coastal
t CO2-e	tonnes of carbon dioxide equivalents
WA	Western Australia

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Executive Summary

The Western Australian Department of Primary Industries and Regional Development (DPIRD) has identified the need to understand greenhouse gas (GHG) emissions from the livestock sector in detail, with a view to developing emission reduction plans for the state. To achieve this, DPIRD commissioned a life cycle assessment (LCA) for the sheep industry in Western Australia (WA) for the financial years (FY) 2005 (July 1, 2004 to June 30, 2005) and 2020 (July 1, 2019 to June 30, 2020). The analysis of one historic period provided a baseline reference point for the more recent results, and the intent was to develop an approach that could be updated into the future. This study followed well-established methods published in peer-reviewed literature for sheep production systems (Wiedemann, Ledgard, et al., 2015; Wiedemann, McGahan, et al., 2015; Wiedemann, Yan, & Murphy, 2016). The study utilised methods from the Australian National Inventory Report (NIR) (Commonwealth of Australia, 2021) for prediction of livestock emissions, and followed international guidance for conducting small ruminant LCA (FAO, 2016). Emissions were reported as Global Warming Potentials (GWP_{100}). Emission estimations were determined from a detailed flock inventory for the stated years, disaggregated by region (using ABARES regions). Within each region, the flock profile was determined from sales records to meat processing, live export and eastern states. Impacts were allocated to live weight (LW) and greasy wool (GW) based on the proportion of protein in each product (after Wiedemann, Ledgard, *et al.*, 2015).

Results were reported as totals for the state flock (tonnes CO_2-e) and emission intensity, reported in kg CO_2-e kg LW^{-1} and kg CO_2-e kg GW^{-1}. Emission intensity results were estimated from underlying flock performance for each year, reflecting a stable flock structure.

Results and Discussion

The study showed a 37% decrease in total emissions from 5,873,332 t CO_2-e in FY 2005 to 3,681,703 t CO_2-e in FY 2020 (Figure 1). The reduction in total emissions was largely due to the reduction in total flock numbers over this time. Impacts were predominantly from enteric methane (78-85%) followed by nitrous oxide (8-9%) and carbon dioxide from energy use and purchased inputs (6-13%).

The enteric methane results presented here were 9.9% and 10.1% higher than the emissions reported in the Australian National Greenhouse Gas Inventory (NGGI) for the respective years (AGEIS, 2020).

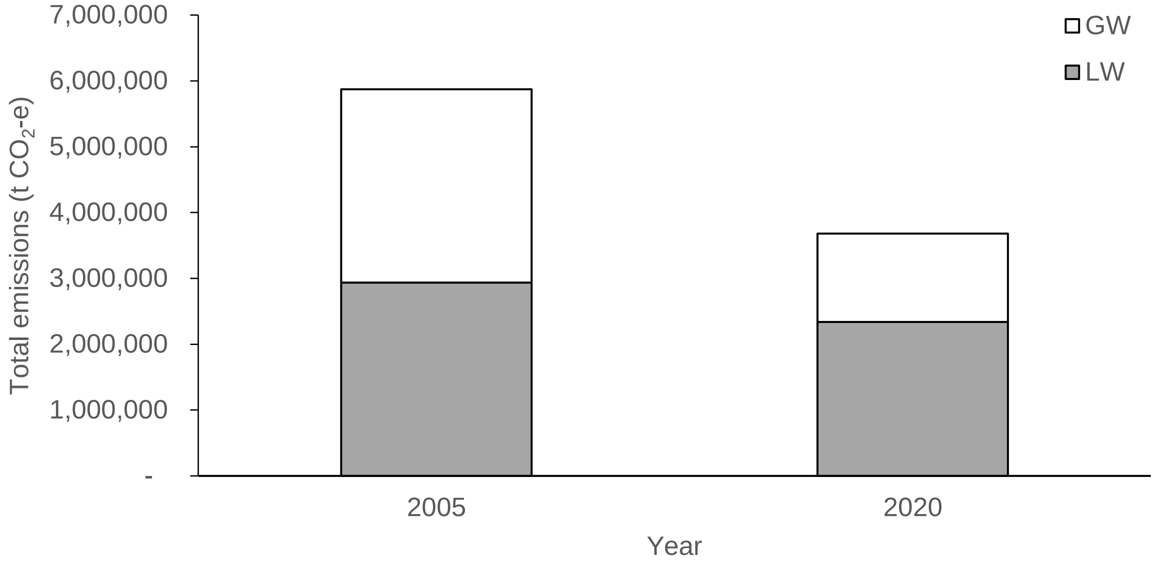

Figure 1. Total emissions (t CO_2-e) for the WA sheep industry for FY 2005 and FY 2020, demonstrating the emissions attributed to liveweight (LW) and greasy wool (GW) production

Emission intensity results revealed a 10-12% increase in impacts, from 7.4 kg CO_2-e kg LW^{-1} in FY 2005 to 8.2 kg CO_2-e kg LW^{-1} in FY 2020. When reported for greasy wool the emission intensity increased from 24.3 kg CO_2-e kg GW^{-1} in FY 2005 to 27.2 kg CO_2-e kg GW^{-1} in FY 2020. These results were similar to previous case study farm analyses in WA.

The increase in emissions was unexpected. The following trends were observed that explained this outcome. Seventy two percent of the increase in emission intensity was explained by the increase in impacts from carbon dioxide, which was related to the use of purchased inputs such as diesel and fertiliser. This suggested that sheep production intensified over the period from FY 2005 to FY 2020, with higher inputs being associated with an increase stocking rates and a shift to greater meat production. Investigation into the key indicators driving this result within ABARES survey data for the years 2001 to 2020 confirmed a general trend towards increasing purchased inputs. Changes in flock performance were also observed. Lamb marking rates and live weight turnoff per ewe increased over the comparison period, while concurrently wool yield declined. This reflected a change towards finer micron sheep with slightly lower wool yields, and a greater emphasis on meat production with higher lamb marking percentages and heavier lambs at turnoff, changing the balance between wool and meat. Both wool and live weight are high-protein products, and to examine biological productivity we also examined total protein production (the sum of protein output in LW and GW per ewe and per DSE). This revealed no meaningful change in in protein production over this time on a dry sheep equivalent (DSE) or breeding ewe basis, showing a compensatory shift in productivity from wool to meat. Investigation into the key indicators driving flock performance and therefore change in emissions for the key years and surrounding years demonstrated little inter-annual variability, suggesting that these findings were reflective of a longer-term trend of flock performance.

Several improvement options for production in WA were explored. The purpose was to provide DPIRD with an understanding of the impacts of production improvements and assist in providing an evidence base to consider emission reduction targets.

The first option explored was the use of anti-methanogenic feed additives within the WA sheep flock. A range of scenarios were examined with different levels of adoption and different feeding strategies. The analysis showed that at maximum adoption (100% of animals supplied with additives) during the summer feed gap period (4 months of the year), reduction in enteric methane was estimated to be 11.6%, and reduction in total emissions was estimated to be 9.1%. Abatement was constrained by the efficacy of the additives, which was estimated to be 35% in a paddock feeding scenario, though this assumption was highly uncertain. Considering 100% adoption is implausible, it appears that improving the efficacy in-field will be critical to improving mitigation potential in the WA flock.

The second option explored increased flock productivity including increasing lamb marking rates, lamb-turn off weights and wool production. The most effective scenario resulted in a reduction in emission intensity to 7.7 kg CO_2-e kg LW^{-1} and 25.5 kg CO_2-e kg GW^{-1}. This was projected by increasing lamb marking rates from 88% to 105%, lamb turnoff weights from 45 to 54 kilograms liveweight, and increasing wool production per breeding ewe from 8.6 kilograms to 9.8 kilograms. Scenarios examining an increase in merino lamb production rather than hoggets for live export showed a very slight increase in emission intensity from this strategy, largely because additional inputs were required to achieve faster growth rates, but slaughter weights remained lower than live export.

Conclusions and Recommendations

This study provided DPIRD with in-depth insight into the GHG emissions of the WA sheep industry, reporting impacts for the total flock and on an emission intensity basis, to assist DPIRD in its commitment to reducing industry greenhouse gas (GHG) emissions into the future. The project demonstrated that without deliberate initiatives to reduce impacts, current industry changes have reduced total emissions from the flock (because of flock reductions) but this has not translated into higher efficiency. Instead, intensification has resulted in higher emission intensities.

Scenario modelling showed that emission intensity could be reduced while improving flock productivity, enabling the dual outcomes of potentially better economic returns and also lower environmental impacts. However, we did not consider the impacts or implications associated with changes in performance and stocking rate, which is another determinant of productivity, and this would be beneficial in future work. This study was constrained to a very small number of scenarios. A wide range of further options could also be examined to explore emission reduction potential at regional scale, covering both livestock production aspects, anti-methanogenic feed supplements and land management to improve soil and vegetation carbon, which was not examined here.

To achieve change into the future, the following activities are recommended:

1. Promote the benefits of increased flock productivity from both a profitability and emissions reduction standpoint. This would be assisted by education on the importance and benefits of emission reduction at the farm level.
2. Identify options for collection of improved data to more accurately identify trends in emissions over time, and to identify the impact of inter-annual variability.
3. Supporting research to develop feeding technologies and improved in-field efficacy of anti-methanogenic feed additives.
4. Supporting work on adoption strategies to assist producers to utilise anti-methanogenic feed additives and pastures.
5. Conduct a survey of soil and vegetation management to augment the analysis here with further insight around soil and vegetation carbon changes, and the impact this has on the livestock carbon account.
6. Implementing the carbon neutral strategy at KRF to act as a demonstration site for industry and planning extension and communication activities to maximise the benefit of this activity.
7. Develop industry wide pathways to emission reduction and investigate a broad suite of carbon storage options for different regions and production systems in WA.
8. Aligning analysis presented here with research in the grains sector to maximise benefits from mixed enterprises.
9. To maintain currency and to monitor progress, we recommend updating the analysis on a two-yearly basis to ensure positive (or negative) changes are identified.

Introduction

Background

Society wide, there has been increasing concern over greenhouse gas (GHG) emissions and their contribution to climate change. Government bodies such as the Department of Primary Industries and Regional Development (DPIRD) in Western Australia (WA) are taking action to seek positive change in this area. DPIRD is the state government department in WA that governs agriculture, food, fisheries and regional development. As part of understanding and in the future assisting industry to reduce GHG emissions, DPIRD commissioned a life cycle assessment (LCA) for sheep production in WA. DPIRD aims to examine how this framework can be used to define, quantify, track and improve sustainability over time throughout the sheep industry in WA. This aligns with other DPIRD initiatives, including organisational carbon neutrality over the next decade for the Katanning Research Facility (KRF) (Wiedemann et al., 2020).

LCA provides a systematic assessment tool that delivers quantified results that can be used to benchmark performance. The LCA will further assist in understanding and identifying current impacts and provide a baseline for assessing future progress.

Overview of the Western Australian Sheep Industry

The Australian sheep industry has a production base of 63.5 million sheep, of this 13.6 million sheep are located in Western Australia (WA) (ABS, 2020b). WA produces approximately 22% of Australia’s wool, making it the third largest producing state in Australia. The majority (82%) of the flocks in WA consist of greater than 500 sheep (AWI, 2019) and Merino is the dominant breed.

Australia’s production regions can broadly be categorised into three regions: high rainfall zone, wheat-sheep zone, and the pastoral sheep zone (Figure 2). These zones are defined by average annual rainfall (a.a.r) which influences the production systems used in each region. A significant proportion of the WA sheep flock is located in the wheat-sheep and high rainfall zones (DPIRD, 2021b).

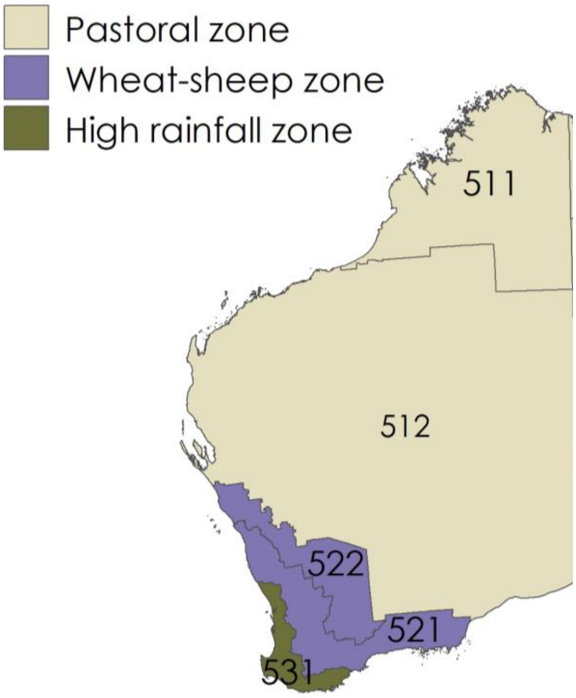

Figure 2. Map of Western Australian showing Australian Bureau of Agricultural and Resource Economics (ABARES) regions. Reproduced from ABARES (2021)

Considering regional differences may influence flock production, market types for sheep and wool, and the level of production intensity, region was considered an important consideration for the study.

Project Objectives

The following project objectives were outlined:

1. Complete an LCA focused on greenhouse gas emissions (carbon footprint) for the West Australian sheep industry.
2. Identify carbon impact hotspots associated with the West Australian sheep industry.
3. Identify information requirements to track environmental performance over time.
4. Explore improvement options for production in Western Australia, allowing the Department to understand and potentially set targets to reduce impacts over time.

Methodology

Project Scope

This project conducted a LCA focused on GHG emissions from the sheep industry in WA for FY 2005 (July 1, 2004 to June 30, 2005) and FY 2020 (July 1, 2019 to June 30, 2020). The LCA included all major sheep production regions of WA including the Central and South Wheat Belt (CSWB), North and East Wheat Belt (NEWB) and South West Coastal (SWC) regions as defined by Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (ABARES, 2021). The main sale destinations including slaughter sheep, sheep transferred interstate and live export sheep were modelled for each of these regions (Figure 3).

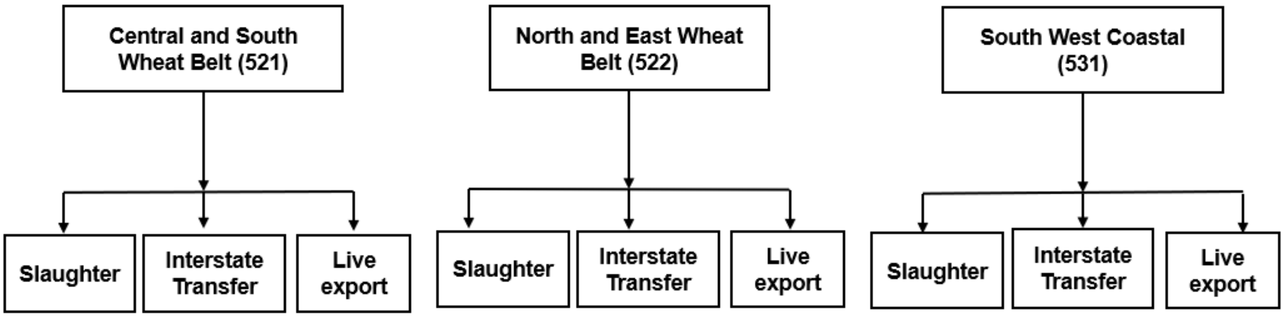

Figure 3. System diagram of the outputs modelled from each sheep producing ABARES region in WA

The LCA examined the farm production system, up to the point at which product is ready to be transported from the farm (i.e. to the farm gate). The farm system boundary included farm services (purchased feed, diesel/ petrol, fertiliser, electricity, administration, and other purchased inputs) including emissions from both pre-farm and on-farm sources, and the livestock system and associated livestock emissions. As a multi-functional system, the reference flows included ‘one kilogram of sheep meat measured as liveweight’ and ‘one kilogram of greasy wool’. Total emissions were also reported for each region. GHG emissions and carbon storage results from land use, direct land use change and land use change were not included in the assessment, partly due to difficulties in attributing these emissions to sheep compared to other land uses such as cattle or cropping.

It is common in Australian grazing environments to base sector wide analyses on the assumption that soil carbon levels are static in grazing environments, though studies have shown both increases in soil carbon in specific instances (Thomas et al., 2012) and decreases in soil carbon (Department of Agriculture and Food, 2013) under WA grazing conditions. On-farm changes in vegetation are more difficult to assess because of limitations around satellite imagery. Based on very limited numbers of case studies this could result in negative emissions (carbon sequestration) of 0.3 to 1.6 kilograms CO_2-e per kilogram of greasy wool (Wiedemann, Yan, Henry, et al., 2016) or 2.0 tonnes per hectare per year (Henry et al., 2015) to 2.4 t CO_2-e per year (Wiedemann et al., 2020). Considering this, it is possible the carbon footprint provided here is slightly over-estimated and future work should consider the role and contribution of soil and vegetation, provided more detailed datasets are available.

Inventory Data

A WA flock inventory was constructed for FY 2005 and FY 2020 using available industry datasets. While total emissions could be reasonably determined from a simple inventory of numbers, calculating emission intensities required a robust assessment of the underlying biological performance of the flock and the output of sheep and greasy wool from a stable flock structure to ensure emissions and flock outputs (wool and live weight) are proportionally correct.

Total emissions were therefore determined based on the standing flock. Because no single dataset presents a complete reconciliation, multiple datasets were combined to provide the flock reconciliation (i.e. ABS, ABARES, DPIRD and PIRSA). This was cross-checked with similar estimates made by DPIRD.

The WA sheep flock inventory in FY 2005 is shown in Table 1. The flock inventory was reconciled with the source datasets, except for closing sheep numbers which were 2% lower than the ABS estimate. It should also be noted that in FY 2005 the WA sheep flock according to ABS estimates was expanding which was an anomaly in the trend for the flock, which has been declining in size for the last 32 years (ABS, 2020a).

Table 1. Reconciliation of the WA sheep flock in FY 2005

	Total	Source Datasets	Notes
Opening number of sheep			
Breeding ewes	**11,477,585**	**11,477,585**	ABS Survey
Ewes joined to Merino rams	6,886,551		Project est.
Ewes joined to terminal rams to produce X bred lambs	4,591,034		Project est.
Breeding ewes not joined	**1,664,760**	**1,664,760**	ABS Survey
Marked lambs under 1 year	**7,274,785**	**7,274,785**	ABS Survey
Merino lambs	4,364,871		Project est.
X bred lambs	2,909,914		Project est.
Other Sheep	**4,645,951**	**4,645,951**	ABS Survey
Total Opening	**25,063,081**	**25,063,081**	ABS Survey
Natural Increase			
Lamb marking rate	82.7%	82.7%	ABS Survey
Merino lambs	5,694,280		Project est.
X bred lambs	3,796,186		Project est.
Total Lambs Marked	**9,490,466**	**9,490,466**	ABS Survey
Turn off			
Lamb Slaughter	2,466,700	2,466,700	ABS Measured
Sheep Slaughter	2,205,200	2,205,200	ABS Measured
Live Export	2,791,374	2,791,374	ABS Measured
Inter-state transfers	-	-	
Total Turn Off	**7,463,274**	**7,463,274**	
Mortality rate	5.0%		ABARES Survey
Losses on farm	1,857,897		
Closing number of sheep	**25,232,376**	**25,592,323**	ABS Survey

The WA sheep flock inventory in FY 2020 is shown in Table 2. All parts of the flock inventory reconcile completely with the source datasets, except for closing sheep numbers which were 5% lower than the ABS estimate.

Table 2. Reconciliation of the WA sheep flock in FY 2020

	Total	Source Datasets	Notes
Opening number of sheep			
Breeding ewes	**7,178,667**	**7,178,667**	ABS Survey
Ewes joined to for Merino rams	4,307,200		Project est.
Ewes joined to terminal rams to produce X bred lambs	2,871,467		Project est.
Breeding ewes not joined	**647,838**	**647,838**	ABS Survey
Marked lambs under 1 year	**4,405,238**	**4,405,238**	ABS Survey
Merino lambs	2,643,143		Project est.
X bred lambs	1,762,095		Project est.
Other Sheep	**2,073,406**	**2,073,406**	ABS Survey
Total Opening	**14,305,148**	**14,305,148**	ABS Survey
Natural Increase			
Lamb marking rate	87.6%	87.6%	DPIRD Estimate
Merino lambs	3,772,566		Project est.
X bred lambs	2,515,044		Project est.
Total Lambs Marked	**6,287,611**	**6,287,611**	ABS Survey
Turn off			
Lamb Slaughter	2,456,500	2,456,500	ABS Measured
Sheep Slaughter	1,770,900	1,770,900	ABS Measured
Live Export	1,065,230	1,065,230	ABS Measured
Inter-state transfers	1,363,239	1,363,239	PIRSA Measured
Total Turn Off	**6,655,869**	**6,655,869**	
Mortality rate	4.5%		ABARES Survey
Losses on farm	995,221		
Closing number of sheep	**12,941,669**	**13,650,129**	ABS Survey

The emission intensity was determined by developing a self-replacing flock structure reflecting underlying performance, where total births were balanced with total sales and mortalities, with no change in the adult sheep population from year to year. In the present analysis, the inventories were re-analysed to adjust total sales to the numbers required to ensure a stable adult population. Because the WA flock was contracting in FY 2020, this resulted in an adjustment to sales to reduce the total output and reflect the number of animals that could be produced while maintaining a self-replacing flock structure.

Flock Output Data

Flock outputs arose from sheep and lambs processed through meat processing plants, sheep sold via live export, and inter-state transfers. On-farm mortalities also represent a non-productive flock output. Australia Bureau of Statistics (ABS) slaughter data were used to determine total head number and total hot standard carcase weight for lambs and sheep in FY 2005 and FY 2020 (ABS, 2020a). Liveweight was then determined assuming dressing percentages appropriate for each sheep class (Meat and Livestock Australia, 2005).

Data from the ABS, supplied by DPIRD provided the number of sheep live exported from WA in FY 2005 and FY 2020 (DPIRD, 2021a). The total gross liveweight of sheep live exported for FY 2020 was determined from ABS data, supplied by DPIRD. The approximate liveweight per head of classes of sheep live exported in FY 2005 and the sale age of these sheep were determined through consultation with industry experts (*pers comm* Hubbard 2021).

DPIRD also provided the number of sheep transferred inter-state from WA in FY 2020 (DPIRD, 2021a). Advice from DPIRD and industry experts determined that there were no inter-state transfers from WA in FY 2005 (*pers comm* Hubbard 2021). The liveweight and sale age of the classes of sheep that were transferred inter-state were also determined through consultation with industry experts (*pers comm* Hubbard 2021).

Advice from DPIRD, industry experts as well as known sale numbers to slaughter, live export and inter-state transfer enabled the determination of the proportion of each sheep class at each end point. The fraction of crossbred to Merino lambs at each end point was determined from the structure of the flock, number of ewes reported as joined to Merino vs other rams, as well as from expert judgement. This proportional breakdown is seen in Table 3. This breakdown allowed the total number of sheep from each end point to be split into the relevant sheep classes.

The known number of sales, estimated mortalities and the change in inventory, was cross checked with lambs marked to close the inventory.

Table 3. Sheep class contribution to each end point for FY 2005 and FY 2020

	Year	1st X lambs	Merino lambs	Merino Wethers	Ewes	Rams	Total
Slaughter	2005	28%	25%	20%	26%	1%	100%
Slaughter	2020	30%	28%	18%	23%	1%	100%
Inter-state Transfer	2020	25%	25%	0%	50%	0%	100%
Export	2005 & 2020	15%	15%	66%	0%	4%	100%

The brokers and dealers receivals of taxable wool figures from ABS were used to define flock wool output (ABS, 2020b). In order to account for yearly fluctuations in wool sold, a wool sales correction was used. In order to determine the wool sales correction ABS wool output was divided by the number of sheep shorn in the WA flock to give a wool cut per sheep shorn value. This was then compared to the wool cut per sheep shorn value reported by ABARES. The ABS wool output was then scaled up or down relative to the ABARES wool cut per sheep shorn. This resulted in a 4% decrease in FY 2005 and a 20% decrease in FY 2020 of the ABS figure (Table 4).

Table 4. Total wool for each financial year showing ABS brokers and dealers receivals and the corrected wool sales amount

	CSWB	NEWB	SWC	Total
FY 2005				
Total wool sold (ABS) (t)	78,537	18,104	10,168	106,809
Sales correction	0.96	0.96	0.96	0.96
Corrected wool (t)	75,120	17,316	9,726	102,162
FY 2020				
Total wool sold (ABS) (t)	47,813	11,940	7,039	66,793
Sales correction	0.80	0.80	0.80	0.80
Corrected wool (t)	38,343	9,575	5,645	53,563

Australian Bureau of Agricultural and Resource Economics (ABARES) Data

Information about breeding flocks was determined using ABARES 'all sheep industries combined' dataset (ABARES, 2021). Key production parameters used from ABARES in constructing the self-replacing WA flock included lamb marking rate, mortality rate and ram inclusion rate, and wool cut compared to wool sold.

Farm purchases data were also sourced from ABARES. In accordance with ISO 14044 (ISO, 2006) recommendations, farming sub-systems were subdivided, and inputs associated with crop production and beef inputs were excluded. Input data were scaled to the appropriate flock size for the WA sheep flock based on dry matter intake (DMI) units. Key purchased input parameters from ABARES include farm fuel use, feed inputs, fertiliser, and services. We note there is some ambiguity in the process of separating impacts on-farm between sub-systems. Further work to refine the dataset specific to each subsystem would be beneficial.

ABARES data were used to determine the proportional breakdown of each regional flock. The regional breakdown of sheep slaughtered, live exported and transferred inter-state was determined by calculating the number of lambs in each region as a proportion of the total lambs in those regions (Table 5). The regional breakdown of wool production was determined by calculating the total wool produced in each region as a proportion of the total wool produced in those regions (Table 5).

Table 5. Regionality breakdown of sheep at each end point and of wool produced

	Year	CSWB	NEWB	SWC
Slaughter, Live Export and Inter-state Transfers	2005	72.7%	15.7%	11.6%
	2020	72.2%	15.6%	12.3%
Wool Produced	2005	73.5%	16.9%	9.5%
	2020	71.6%	17.9%	10.5%

Key Production Parameters

Key production parameters that were used to determine emission intensity are summarised below in Table 6 and parameters used to determine total emissions are summarised in Table 7.

Breeding sheep were assumed to be kept on farm for 365 days (all year) unless they were sold as cull-for-age or as transfers. The number of replacement ewes, wethers and rams was determined from the flock requirements, based on sale numbers of sheep and mortalities.

Ewe cull rate was determined by ensuring the number of ewes sold within the flock equalled the total number of ewe sales determined to be present in the slaughter, live export and inter-state transfers.

Clean wool yield was sourced from the Australian Wool Testing Authority's (AWTA) key test data seasonal reports (AWTA, 2021). The clean wool yield used for FY 2005 and FY 2020 were from the 2008/2009 (the closest available period) and 20019/2020 seasonal reports respectively.

The DSE of the WA flock was determined from total feed intake of the flock converted into DSE, which was used as universal comparison for flock performance.

Table 6. Key sheep production parameters for FY 2005 and FY 2020 for the self-replacing flock

	Unit	2005	2020
Lamb marking rate	%	82.7%	87.6%
Sheep mortality rate	%	5.0%	4.5%
Breeding ewe culling rate	%	13%	12%
Clean wool yield	%	59.0	59.9
Sales per ewe joined	no.	0.74	0.79
Ewe mature weight	kg	54	60
Lamb sale weight	kg	43	45
Greasy wool sales per DSE	kg	5.4	4.6
Live weight sales per DSE	kg	18.8	20.4
Protein production per DSE	kg	6.9	6.6
Greasy wool sales per breeding ewe	kg	10.0	8.9
Live weight sales per breeding ewe	kg	34.6	39.3
Protein production per breeding ewe	kg	12.7	12.8

Table 7. Key sheep production parameters for FY 2005 and FY 2020 for the standing flock

	Unit	2005	2020
Lamb marking rate	%	82.7%	87.6%
Sheep mortality rate	%	5.0%	4.5%
Breeding ewe culling rate	%	11%	14%
Clean wool yield	%	59.0	59.9
Sales per ewe joined	no.	0.65	0.93
Ewe mature weight	kg	54	60
Lamb sale weight	kg	43	45
Greasy wool sales per DSE	kg	4.9	4.5
Live weight sales per DSE	kg	16.2	26.1
Greasy wool sales per breeding ewe	kg	8.9	7.5
Live weight sales per breeding ewe	kg	29.2	43.3

Greenhouse Gas (GHG) Estimation

GHG emissions were modelled by region for sheep (enteric methane and manure emissions) and for purchased inputs (fuel, electricity, feed, purchased cattle etc.).

Feed intake, enteric methane and manure emissions were determined using methods consistent with the NIR (Commonwealth of Australia, 2021). Inventory data related to dietary crude protein, dry matter digestibility and dry matter availability used in estimation of manure emissions, used regional assumptions from the NIR (Commonwealth of Australia, 2021).

The inventory modelling was completed using SimaPro 9.0 (Pré-Consultants, 2020), with the impact assessment using Global Warming Potential Values (GWPs) from the IPCC Fifth Assessment Report (AR5) as outlined in the National Greenhouse Accounts (Commonwealth of Australia, 2020) (Table 8). Emissions were reported as carbon dioxide equivalents (CO_2-e). This unit was used to compare emissions from different GHGs based on their global warming potential (GWP) over a specified period, typically 100 years (GWP_{100}).

Table 8. Global Warming Potential (GWP_{100}) values relative to CO_2 (Myhre et al., 2013)

Greenhouse Gas	Chemical Formula	Fifth Assessment Report (AR5)
Carbon Dioxide	CO_2	1
Methane	CH_4	28
Nitrous Oxide	N_2O	265

Handling Co-Production

There are several points in the production system where co-products were produced. This study follows the methods outlined in Wiedemann, Yan, and Murphy (2016) to divide burdens between sub-systems at the farm scale. Within the WA sheep industry, beef, sheep and cereals were sometimes co-produced on the same farms. These were treated as sub-systems, and inputs associated with cropping were first deducted based on the area of cropland sown annually. Inputs associated with sheep and cattle were then divided based on the stocking rate of each, expressed per DSE. Manure nutrients from the grazing herd were assumed to return directly to pasture and were therefore considered a biological feedback loop, without the need for allocation.

Production of sheep and wool cannot be sub-divided and were treated using allocation rules for co-production. This applied the protein mass allocation method (Wiedemann, Ledgard, et al., 2015).

Results

Total Emissions

Total emissions from the WA sheep flock were the product of total sheep production (i.e. liveweight and greasy wool) and the relative GHG efficiency of the sheep flock (i.e. emission intensity). Total emissions declined 37% from FY 2005 to FY 2020, from 5,873,332 t CO_2-e in FY 2005 to 3,681,703 t CO_2-e in FY 2020 (Figure 4). This decline was largely in response to the reduction in flock numbers from 25 million in FY 2005 to 13.6 million in FY 2020 (Table 2).

Emissions from liveweight sold and greasy wool sold contributed similar amounts to total emissions in 2005 (50% impacts to both products), but this ratio moved strongly to live weight in 2020 (64%) with the increased proportion of liveweight to wool in this year (Figure 4) .

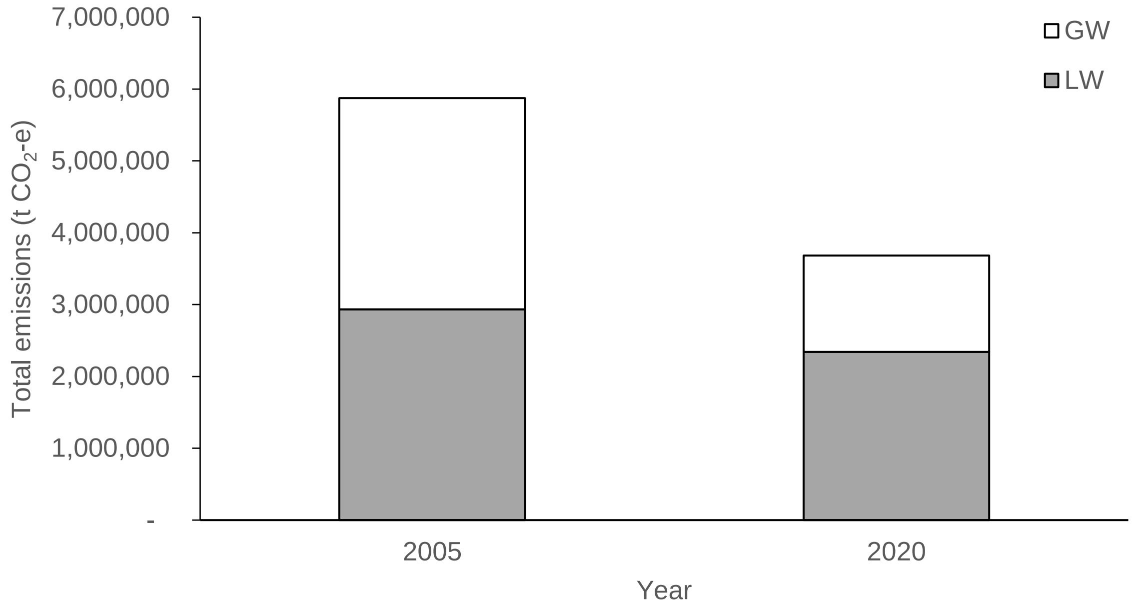

Figure 4. Total emissions (t CO_2-e) for the WA sheep industry for FY 2005 and FY 2020 , showing the attribution to liveweight (LW) and greasy wool (GW) production

Emission Intensity

The analysis revealed a 9% increase in GHG emission intensity for the WA sheep industry from FY 2005 (7.4 kg CO_2-e kg LW^{-1}) to 8.2 kg CO_2-e kg LW^{-1} in FY 2020 (Figure 5). Emissions were dominated by enteric methane (CH_4) (79-85%), followed by nitrous oxide (N_2O) and carbon dioxide (CO_2) (6-12%). The increase in emissions over this time was primarily associated with an increase in carbon dioxide emissions from 0.4 to 1.0 kg CO_2-e kg LW^{-1} from purchased inputs.

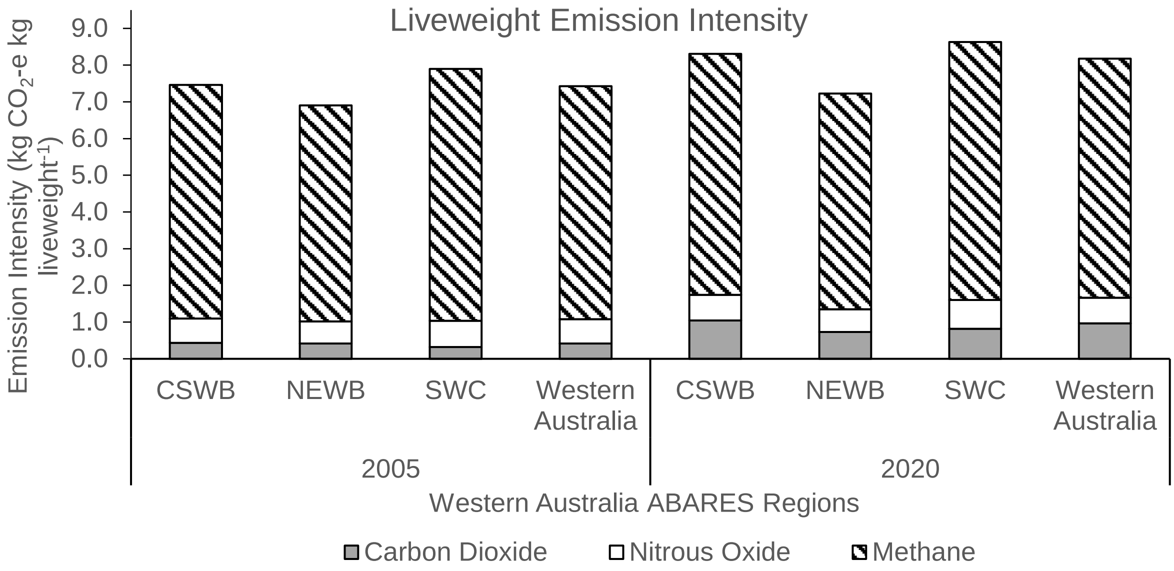

Figure 5. GHG emission intensity (kg CO_2-e per kg of liveweight) for the WA sheep industry across the WA ABARES regions of Central and South Wheat Belt (CSWB), North and East Wheat Belt (NEWB) and South West Coastal (SWC) and a weighted average across these three regions

Wool emission intensities were 24.3 kg CO_2-e kg GW^{-1} in FY 2005 and 27.2 kg CO_2-e kg GW^{-1} in FY 2020 (Figure 6). As with live weight, the increase in emissions over this time period was associated with an increase in carbon dioxide from purchased inputs (from 1.4 to 3.2 kg CO_2-e kg GW^{-1}).

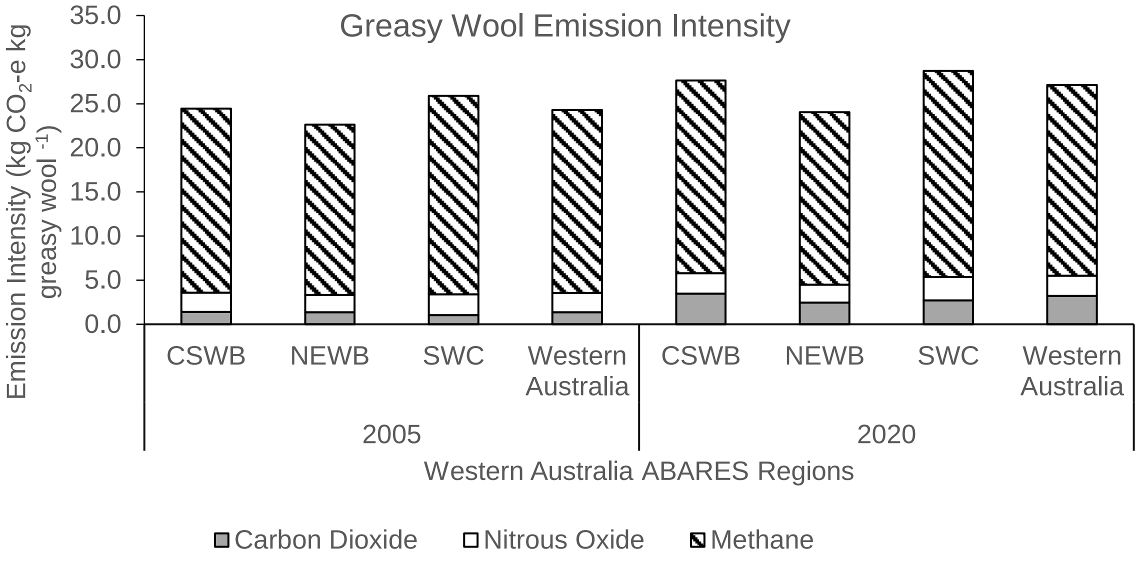

Figure 6. GHG emission intensity (kg CO_2-e per kg of liveweight) for the WA sheep industry across the WA ABARES regions of Central and South Wheat Belt (CSWB), North and East Wheat Belt (NEWB) and South West Coastal (SWC) and a weighted average across these three regions

It should be noted that the reported emission intensity was determined from a self-replacing flock. Multiplying emission intensity results with outputs from the flock will not result in equivalent emissions to the totals reported in the previous section.

Carbon Impact Hotspots

A carbon impact hotspot analysis was conducted to identify the main sources of emissions within the WA sheep industry. Enteric methane emissions from sheep dominated the emissions profile for the WA sheep industry in both FY 2005 (85%) and FY 2020 (79%). From FY 2005 to FY 2020 there was a significant increase in impacts from carbon dioxide (6-12%) which was related to an increase in the use of purchased inputs such as diesel.

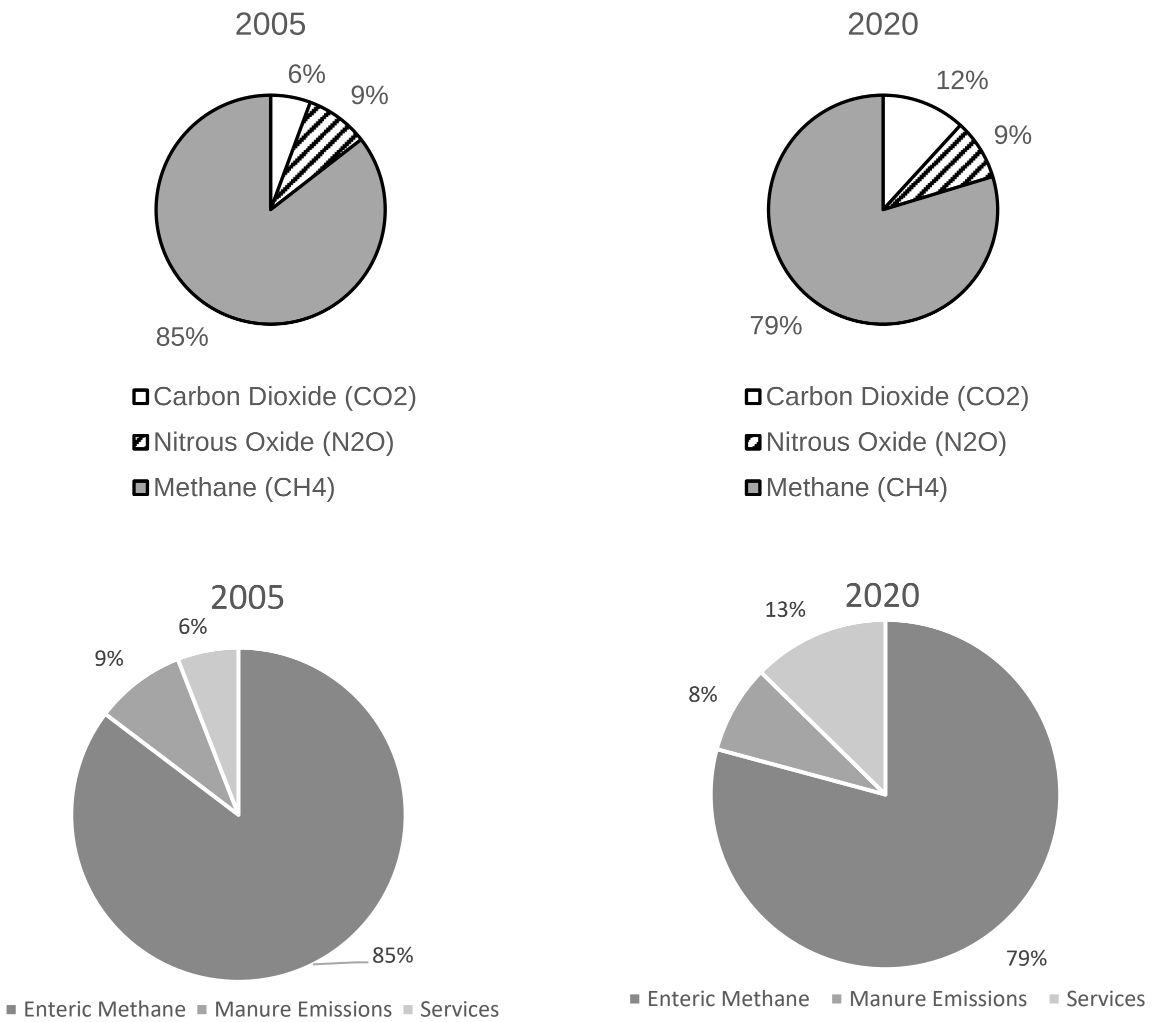

Figure 7. Western Australia emissions contribution analysis, FY 2005 and 2020

Discussion

Flock Productivity

Flock productivity and breeding objectives have changed in the WA sheep industry over the past 15 years. Most notable is a substantial shift from wool to lamb production. This analysis revealed no meaningful change in protein output from the flock between 2005 to 2020. There were multiple drivers for this: lamb marking rates improved and turnoff weight of lambs increased (see Table 9), but wool cut per head decreased, counteracting any improvement in overall productivity.

In FY 2005 the WA flock produced 5.4 kg of greasy wool per DSE and 18.8 kg of liveweight per DSE, compared to 4.6 kg of greasy wool per DSE and 20.4 kg of liveweight per DSE in FY 2020. The trend of declining wool production led to a higher proportion of the impacts being allocated to sheep meat. Overall, from FY 2005 to FY 2020 the protein production of the WA flock showed no meaningful change.

The trend of reduction in wool cut was also reflected in the ABARES dataset. When the ABARES wool cut per sheep shorn was weighted across the three WA sheep production regions based on head number in each regions there was a reduction in wool cut from 4.5 to 3.8 kg (15%) from FY 2005 to FY 2020. This trend was also seen in reductions in total production, though this was principally influenced by reduced flock numbers.

This reduction in wool cut was also related by a reduction in wether sheep numbers, which declined 37% as a percentage of the total WA flock. Lower fibre diameter, and therefore lower micron wool was seen in the decrease from 20.5 in FY 2005 to 19.2 in FY 2020 (AWTA, 2021) which was a contributing factor to lower wool yields. The increase in lamb marking rate from 82.7 to 87.6% may also have contributed to slightly lower wool cut from breeding ewes.

The increase in liveweight production was demonstrated by several performance indicators of the WA flock. Within the ABS slaughter statistics there was a clear increase in sheep and lamb carcase weight from FY 2005 to FY 2020. Hot standard carcase weight (HSCW) increased 8% in lambs, and 22% in sheep.

An investigation into the key indicators informing this part of the result for FY 2005 and FY 2020 and the surrounding years was conducted (Table 9). This showed little variation in the key indicators inter-annually but did show a longer-term trend from FY 2005 to FY 2020. This suggested that the change in emissions reflected a long-term trend in improved flock performance.

Table 9.Comparison of key indicators influencing emission intensity from FY 2005 and FY 2020 and surrounding years

Year	Lamb marking rate (%)	Mortality rate (%)	Wool cut per sheep shorn (kg)	Wool produced per ewe mated (kg)	Lamb Slaughter Weight (HSCW)
2001	71%	6.6%	4.40	10.38	18.35
2002	77%	4.3%	4.32	9.20	19.18
2003	81%	4.9%	4.48	9.22	19.58
2004	83%	4.5%	4.51	9.39	19.74
2005	***83%***	***5.0%***	***4.48***	***9.52***	***19.91***
2006	82%	5.1%	4.30	9.91	20.75
2007	73%	6.5%	4.05	8.79	20.06
2017	89%	3.8%	4.37	9.59	21.80
2018	91%	4.3%	4.30	9.96	20.33
2019	85%	4.7%	4.02	8.88	20.87
2020	***88%***	***4.5%***	***3.83***	***8.40***	***21.53***

Greenhouse Gas (GHG) Emissions

Total Emissions

Flock inventories and GHG modelling conducted in this study were independent of analyses done by DPIRD and by the National Greenhouse Gas Inventory. Comparing these findings, total enteric methane emissions for FY 2005 were 9.9% higher here than reported in the NGGI in FY 2005. Total enteric methane emissions for FY 2020 were 10.1% higher than that reported in the NGGI for FY2019 (Figure 8) (AGEIS, 2020). This study reported higher emissions due to the flock inventory and key productivity parameters differing from the NGGI assumptions. Ewe, ram and lamb liveweight and lamb liveweight gain in this study were all higher than what is used in the NGGI, and sheep numbers may be higher. Considering the live weight assumptions used here are well founded from new data sources that haven’t been considered by the NGGI, the assumptions could be provided as an update to NGGI activity data. As well as this, a nuanced approach has been used to determine head days for each sheep class in this study, an approach which is not used in the NGGI.

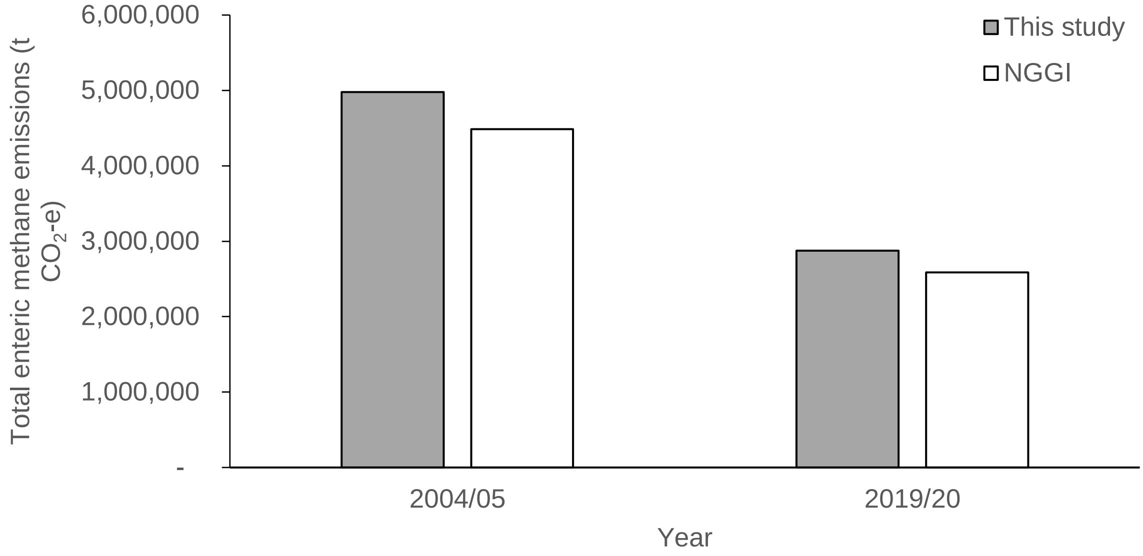

Figure 8. Total enteric methane emissions (t CO_2-e) in this study compared to the National Greenhouse Gas Inventory (NGGI) figures

Emission Intensity

This study reported an increase in emission intensity, which was contrary to what the industry aims to achieve. The most notable trend was associated with reported intensification of the production system. This study also found a noticeable shift from wool to meat production from FY 2005 to FY 2020 which overall resulted in no meaningful change in protein production. This shift from wool to meat production may somewhat explain the increase in production intensity as meat production is expected to require greater amounts of purchased inputs than wool production.

This was exemplified in a 132% increase in impacts from carbon dioxide from FY 2005 to FY 2020 related to purchased fuel and other inputs. In FY 2005 carbon dioxide accounted for 6% of the impacts compared to 12% in FY 2020. This explained 72% the increase in emission intensity between the years. To investigate whether this result is a product of a long-term trend or as a result of inter-annual variability, key indicators from the ABARES datasets were compared for the key years and their surrounding years. This found some variation in diesel amounts year on year but a more noticeable long term increase from FY 2005 to FY 2020 suggesting the change in emissions is likely a product of a long-term trend.

ABARES datasets showed slightly higher stocking rates in the more recent time period. Previously Wiedemann, Yan, Henry, *et al.* (2016) found that farms with higher stocking densities had higher purchased inputs and the benefit to livestock performance outweighed the added impacts from purchased inputs. However, in this case this did not occur. Other factors may also have influenced this result: sheep have declined and cropping has expanded over the analysis period, and it is possible that sheep are now run on more marginal country requiring higher inputs to maintain productivity. It is also possible that the increased incidence of drought, partly arising from changes in long-term climate, have resulted in higher supplementary feed requirements. These possibilities would require further analysis to confirm the trend.

The results from region to region and from FY 2005 to FY 2020 reflect the state wide trend of increasing emission intensity. The NEWB region was the best performing region in both FY 2005 and FY 2020. This region had an emission intensity of 6.9 kg CO_2-e kg LW^{-1} and 22.6 kg CO_2-e kg GW^{-1} in FY 2005 and 7.2 kg CO_2-e kg LW^{-1} and 24.1 kg CO_2-e kg GW^{-1} in FY 2020 (Figure 5 and Figure 6). This region was the best performing as it produced the largest amount of wool, liveweight and protein per DSE. The SWC region was the worst performing region in both FY 2005 and FY 2020. This region had an emission intensity of 7.9 kg CO_2-e kg LW^{-1} and 25.9 kg CO_2-e kg GW^{-1} in FY 2005 and 8.7 kg CO_2-e kg LW^{-1} and 28.8 kg CO_2-e kg GW^{-1} in FY 2020 (Figure 5 and Figure 6). This region had the lowest performance and produced the smallest amount of wool and protein per DSE.

Comparison to Other Studies

The emission intensity of the WA sheep flock in FY 2005 was similar to the values reported by Wiedemann, Yan, Henry, *et al.* (2016) when updated with the most recent GWP_{100} values. The values reported in this paper were best compared to FY 2005 as the production data to inform the regional average farm (RAF) was from between 2006 and 2010. The case study farm (CSF) data was collected in 2012 and 2013 meaning it was close to the mid-point of the results presented here from a chronological perspective. As seen in Figure 9, the mean emission intensity results per kilogram of liveweight were very similar, where FY 2005 was 0.7% lower than the WA wheat sheep zone RAF and 1.8% higher than the wheat sheep zone CSF.

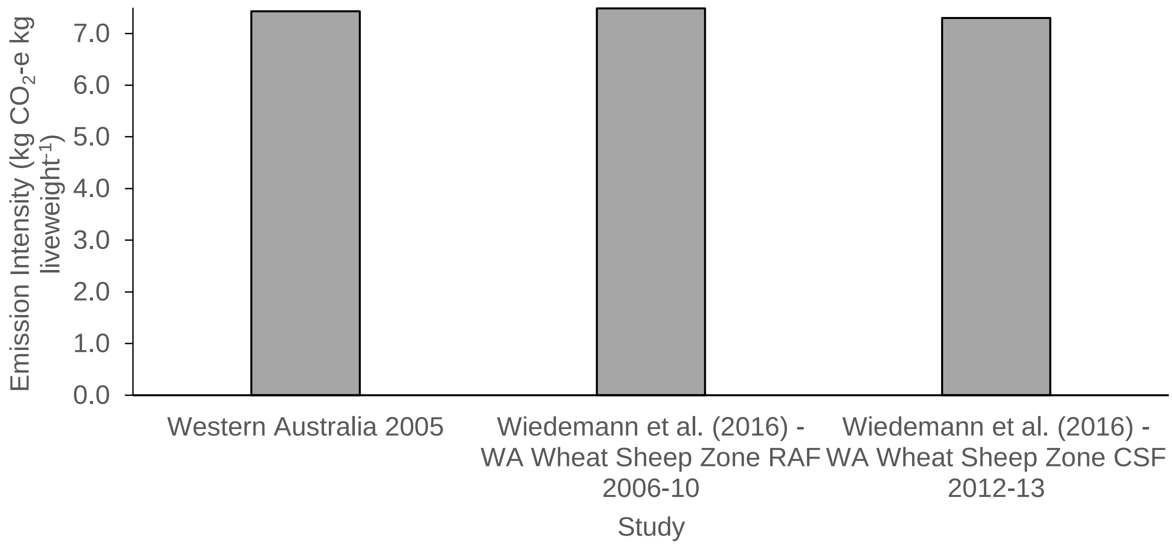

Figure 9. Emission intensity comparison (kg CO_2-e kg liveweight^{-1}) between FY 2005 of this study and Wiedemann, Yan, Henry, *et al.* (2016)

As seen in Figure 10, the mean emissions intensity per kilogram of greasy wool in FY 2005 were between 9 and 11% lower than the WA wheat sheep zone CSF and RAF respectively from Wiedemann, Yan, Henry, *et al.* (2016). The WA RAF and CSF tended to perform better in terms of production per DSE. The RAF produced 5% more greasy wool per DSE, 9% more liveweight and 8% more protein. The CSF produced 17% more liveweight and 0.2% more protein. However, despite this improved production the emission intensities for the RAF and CSF were higher than FY 2005 due to the greater impacts from carbon dioxide associated with increased purchased inputs. Impacts from carbon dioxide was between 52 and 229% higher for the CSF and RAF than FY 2005.

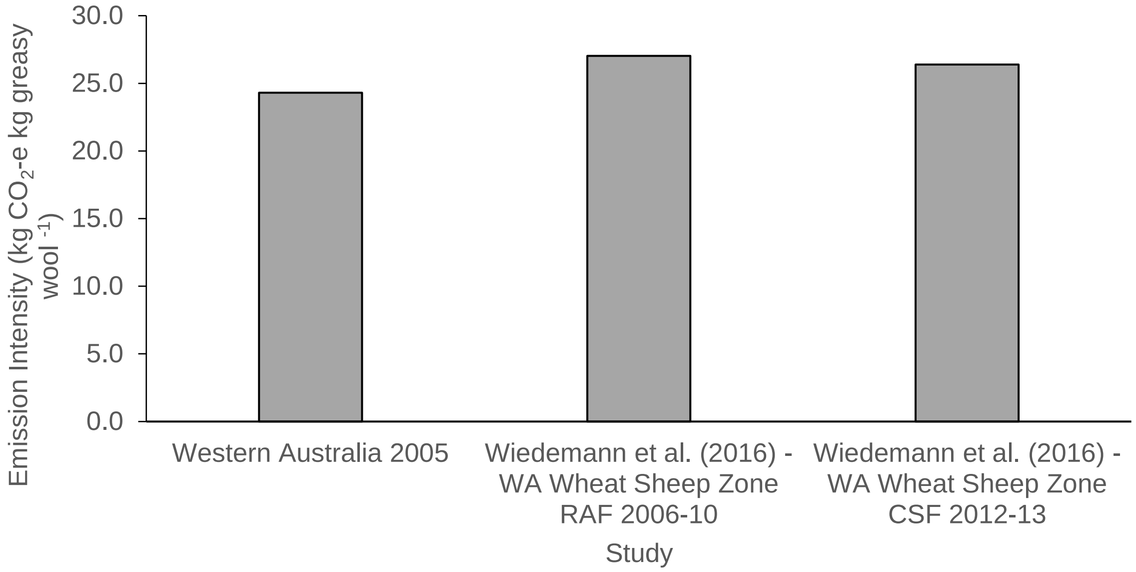

Figure 10. Emission intensity comparison (kg CO_2-e kg greasy wool^{-1}) between FY 2005 of this study and Wiedemann, Yan, Henry, *et al.* (2016)

The current study results were also compared to those from the Katanning Research Facility (KRF) Carbon Footprint Assessment (Wiedemann et al., 2020). The KRF is located in the CSWB region. The FY 2020 emission intensity per kilogram of liveweight was 16% lower than KRF in 2018 and 21% lower than the KRF in 2019. The FY 2020 CSWB emission intensity per kilogram of liveweight was 14% lower than the KRF in 2018 and 19% lower than the KRF in 2019 (Figure 11). The FY 2020 emission intensity per kilogram of greasy wool was 11 and 16% lower than the KRF in 2018 and 2019 respectively. The FY 2020 CSWB emission intensity per kilogram of greasy wool was 9 and 14% lower than the KRF in 2018 and 2019 respectively. (Figure 12).

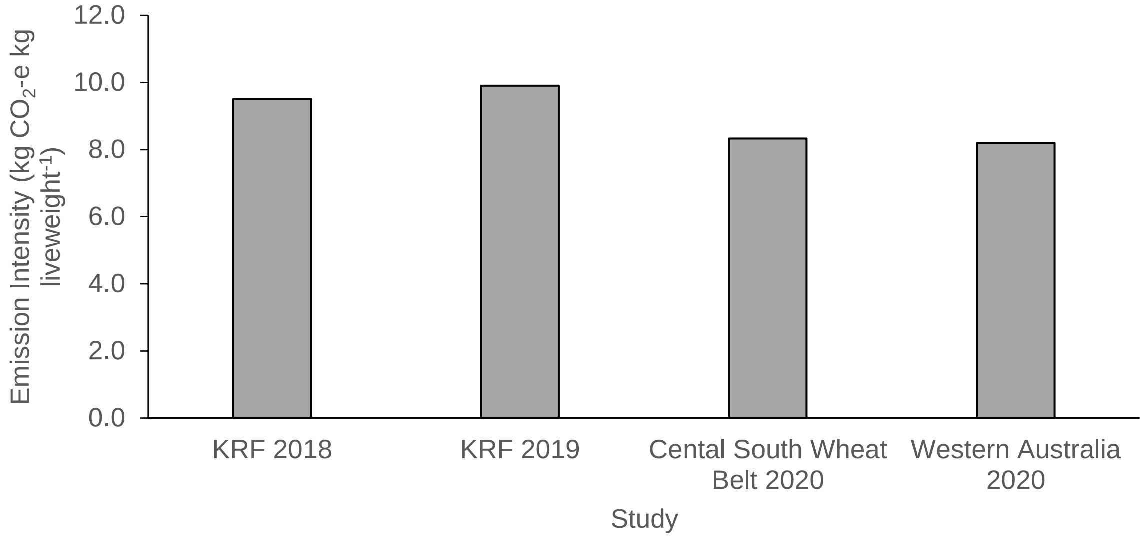

Figure 11. Emission intensity comparison (kg CO_2-e kg liveweight^{-1}) between FY 2020 of this study and the Katanning Research Facility (KRF)

There were two key reasons for the difference in emission intensity between these two studies. The first was the greater impacts from carbon dioxide which was associated with greater purchased inputs at KRF than the regional average. The impacts from carbon dioxide were between 4 and 52% greater for the KRF compared to the CSWB region in FY 2020. The impacts from carbon dioxide were between 10 and 61% greater for the KRF compared to the WA in FY 2020. The second reason for the differences in emission intensity was the difference in greasy wool production. KRF produced between 10 and 50% less greasy wool per breeding ewe than the CSWB in FY 2020. As well as between 13 and 53% less greasy wool per breeding ewe than WA in FY 2020. This resulted in higher emission intensities because the maintenance requirements and emissions from the flock was divided across less output.

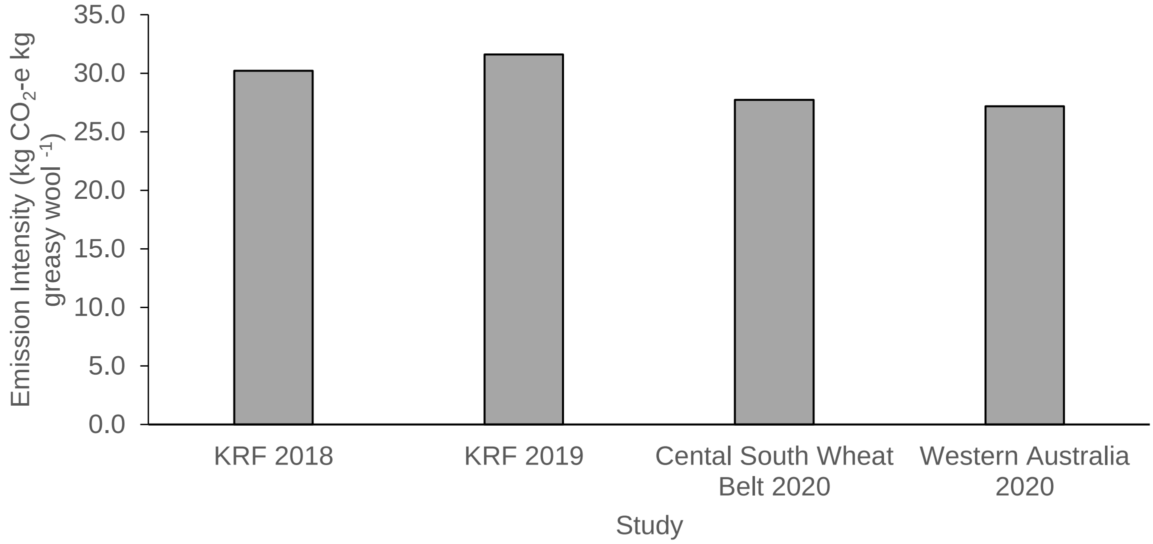

Figure 12. Emission intensity comparison (kg CO_2-e kg greasy wool^{-1}) between FY 2020 of this study and the Katanning Research Facility (KRF)

Few other case studies have been completed using contemporary data in WA, and this remains a gap in the knowledge base. Expanding the benchmarking of carbon footprints would build the knowledge base and reveal lower impact producers, which could be used as case studies for management that is suited to reducing emissions.

Western Australian Land Use Change

This study did not include emissions and sequestration from soil or vegetation sources in the carbon footprint, because of the lack of farm-scale data to quantify this as well as difficulties in attributing these to sheep compared to other land uses such as cattle and cropping.

To gain insight into the potential carbon sequestration, the National Inventory data for WA were reviewed, which revealed that from FY 2005 to FY 2019 WA moved from emitting carbon (8.6 Mt CO_2-e) to sequestration (-8.6 Mt CO_2-e) (AGEIS, 2020).

The largest driver of this change in emissions was attributed to cropland moving from emitting carbon in FY 2005 (2.1 Mt CO_2-e) to sequestration in FY 2019 (-4.5 Mt CO_2-e) (318% change) (AGEIS, 2020). Cropland remaining cropland has remained sequestering carbon from FY 2005 to FY 2019. Whereas land converted to cropland (i.e. from forest land and wetland) continues to emit carbon, although this has reduced from 2.7 to 1.0 Mt CO_2-e (63% change). The land use category Cropland in the National Inventory is all land that is under rotation with crops so includes all of the broad acre agricultural region.

The other large contributor to this change in emissions was from grasslands, although only a very small fraction of grasslands is grazed by sheep in WA (grasslands are predominantly in the pastoral lands with a small fraction on the high value coastal plain where beef and dairy predominate). Grasslands overall moved from emitting 9.7 Mt CO_2-e in FY 2005 to emitting 1.3 Mt CO_2-e (87% change) (AGEIS, 2020). Grassland remaining grassland has moved from emitting carbon to sequestering since FY 2005 and is now reported to sequester 1.7 Mt CO_2-e annually (AGEIS, 2020). The main driver of this change was regrowth of sparse woody vegetation (regeneration), which was emitting 0.3 Mt CO_2-e of carbon in FY 2005 and in FY 2019 this was -3.0 Mt CO_2-e (AGEIS, 2020).

One source of carbon sequestration that may be underrepresented in the National Inventory is on-farm tree planting (e.g. shelter belts). This is because the resolution of assessment used by the National Inventory most likely does not identify these small tree planting areas and is therefore likely to be underestimating sequestration from plantings such as these. The current contribution of these sources to the carbon balance of a farm is poorly understood. Henry *et al.* (2015) found that shelter belts on a WA sheep farm may sequester carbon equivalent to around 2% of the emissions from sheep, when annualised over a 100-year timescale. This would be a more appreciable 6% if annualised over a shorter period (30 years) that more closely aligned to the active growing period of the trees. Anecdotal evidence from farmer case study workshops conducted by DPIRD and Integrity Ag and Environment in 2020 suggested some farms may have planted up to 10% of land area to trees, and that more potential existed. This would most likely result in more significant levels of carbon sequestration, approaching 30-50% of livestock emissions.

Scenarios for reducing impacts

The following analysis assessed possible improvement options for production in WA and their potential impacts on GHG emissions for the WA sheep industry. These improvement options may allow DPIRD to set targets to reduce emissions over time.

Anti-methanogenic Feed Additives

Anti-methanogenic feed additives target the pathway of methanogenesis and thus have the ability to reduce enteric methane production. Two scenarios were analysed to demonstrate the potential impact of the use of anti-methanogenic feed additives in the WA sheep flock compared to FY 2020.

The first scenario assumes the anti-methanogenic additive is 35% effective. This is an estimate as field efficacy is currently unknown for the most prospective additives and is based on a reduced trial efficacy, assuming in-field impacts will result in lower methane reductions. The first scenario also assumes 50% adoption of this technology within the WA flock for 33% of the year, representing the time for feeding during the annual feed gap. This would amount to a 5.8% reduction in enteric methane emissions (Figure 13). The second scenario also assumes an efficacy of 35%, with 100% of the WA flock adopting this technology for 33% of the year. Overall, this amounts to a 11.6% reduction in enteric methane emissions (Figure 13). This change in total enteric methane in scenario one would also have the impact of reducing total emissions by 4.5% and by 9.1% in scenario two.

It is important to note that the use of anti-methanogenic additives at a level great enough to make an impact on emissions may not occur until at least 2030. Even when such a level is reached the total impact of these additives are unlikely to make a significant difference to overall emissions. Two barriers exist with respect to greater reductions in methane from feed additives: feeding technology and in-field efficacy. These are important, ongoing areas of research and for the industry to significantly reduce emissions these problems need to be overcome.

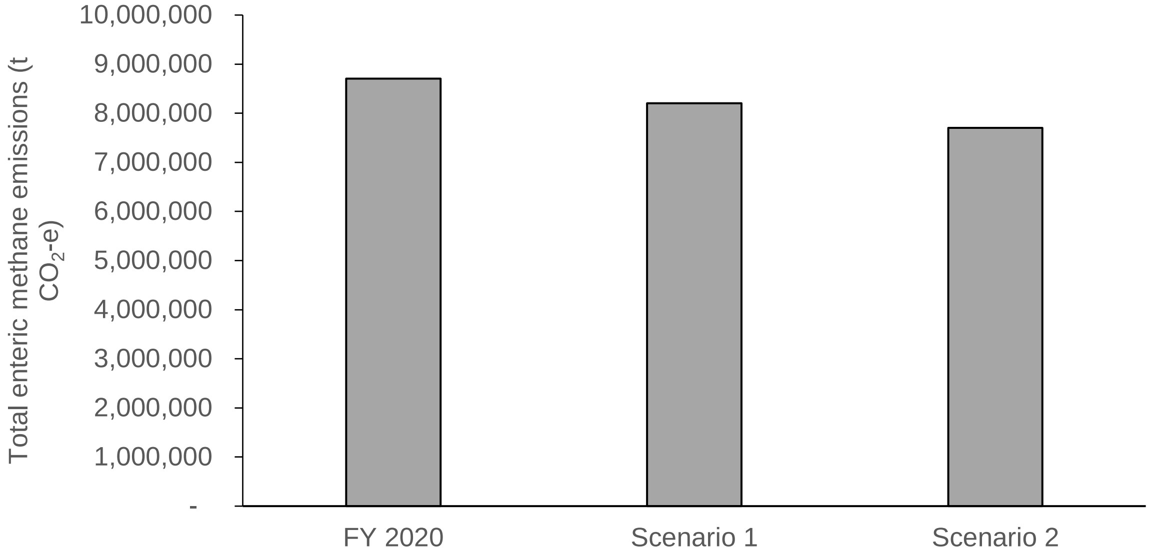

Figure 13. Anti-methanogenic additive use scenarios comparing total enteric methane emissions (t CO_2-e) results with FY 2020

Productivity Improvements

A number of different scenarios have been analysed to demonstrate the potential impacts of different productivity increases on emission intensity (kg CO_2-e kg LW^{-1} and kg CO_2-e kg GW^{-1}) compared to emission intensity in the FY 2020 in this study.

As seen in Table 10 productivity increases of any magnitude in lamb marking rate, lamb turn off weight or wool production per breeding ewe have the impact of reducing emission intensity. The greatest impact on emission intensity was achieved in scenario five with a 20% increase in lamb marking rate, 20% increase in lamb turn off weight and 10% increase in wool production per breeding ewe.

Table 10. Productivity improvement scenarios comparing emission intensity (kg CO_2-e kg LW^{-1} and kg CO_2-e kg GW^{-1}) results with FY 2020. The percentage increase is shown in brackets.

	FY 2020	Scenario 1	Scenario 2	Scenario 3	Scenario 4*	Scenario 5
Lamb marking rate	88%	90% (2.5%)	92 (5%)	96 (10%)	96 (10%)	105% (20%)
Lamb turnoff weight (kg)	45	47 (5%)	49 (10%)	49 (10%)	49 (10%)	54 (20%)
Wool production/breeding ewe (kg)	8.9	9.2 (3%)	9.2 (3%)	9.3 (5%)	9.8 (10%)	9.8 (10%)
Emission Intensity (kg CO_2-e kg LW^{-1})	8.2	8.1	8.0	7.9	7.7	7.7
Emission Intensity (kg CO_2-e kg GW^{-1})	27.2	26.7	26.6	26.3	25.7	25.5
Carbon Dioxide (CO_2)	11.8%	11.6%	11.4%	11.4%	11.4%	11.0%
Nitrous Oxide (N_2O)	8.5%	8.5%	8.5%	8.5%	8.5%	9.0%
Methane (CH_4)	79.5%	79.6%	79.8%	79.9%	79.9%	80.0%

*this scenario also looked at the impact of increase wether sale weights 3% to 55kg liveweight

Another scenario was conducted which investigated the impact of the wethers sold in the self-replacing flock being sold as lambs. Compared to FY 2020 this scenario resulted in a 5% increase in emission intensity, because live weight production was lower and additional inputs were required to meet the weight specifications for a lamb carcase at an earlier age (Table 11). These results were governed by the assumptions used. If it was possible to achieve heavy lamb weights, similar to live-export weights then it may be possible to reduce emission intensity while shifting from live export to lambs. However, this would require feeding lambs for a longer period over summer and into autumn to achieve these weights before reaching hogget ages.

Table 11.Emission intensity results of the scenario where wethers are sold as lambs

	Scenario
Emission Intensity (kg CO_2-e kg LW^{-1})	8.6
Emission Intensity (kg CO_2-e kg GW^{-1})	28.6
Carbon Dioxide (CO_2)	11.9%
Nitrous Oxide (N_2O)	8.5%
Methane (CH_4)	79.3%

Information Requirements to Track Environmental Performance

This study relied on data from several different datasets (i.e. ABS, ABARES, NIR) to construct the flock model from which GHG predictions were made. Data needed that was not available from these datasets were sourced from either consultation with industry experts, or assumptions, which introduced a degree of uncertainty into the prediction of emissions.

The key data gaps identified were expanded on below and bring attention to the need for improved data gathering to ensure the improved quality of GHG emission estimation. One of the most significant data gaps that existed in this study was the sale weights and age of all sheep being transferred inter-state in FY 2005 and FY 2020 and exported from WA in FY 2005. Another knowledge gap was the breakdown of the classes, age and breed of sheep that were being sold to each end point (i.e. slaughter, inter-state transfer, export).

While these data gaps were not expected to result in large uncertainties in the results, it would be beneficial to survey on these characteristics annually. Improved data quality of this type and regular updates to this data would allow for much greater accuracy and sensitivity in GHG emission estimation of the WA sheep flock in the future.

Conclusions and Recommendations

This study has provided a life cycle assessment (LCA) for the sheep production industry in WA and consequently provides an in depth insight into the GHG emissions of the WA sheep industry. The LCA was conducted over two time periods, FY 2005 and FY 2020, allowing FY 2005 to be used as a benchmark for future performance.

The analysis revealed that the emission intensity of the flock had increased (9%) due to increased production intensity (higher inputs) from FY 2005 to FY 2020. As shown in other analyses, total emissions have declined significantly over time in response to the reduction in sheep numbers.

Improvement options for production in WA demonstrated that the use of anti-methanogenic feed additives can contribute to emission reduction, but the overall quantum may be lower than hoped for, without breakthroughs in feeding technology and in-field efficacy. The analysis also demonstrated that productivity improvements from increased lamb marking rates, lamb turn-off weights and wool yield can have a positive impact on emission intensity.

It should be acknowledged that this analysis does not consider profitability. Although trends in this analysis suggest a reduction in productivity there are other clear profit drivers that have been present throughout the analysis period that are not reflected in this type of analysis such as finer micron wool and increased proportion of cross bred lambs. Therefore, it is important to recognise that although focus on productivity per hectare in WA is the most profitable way of managing the sheep flock, this approach may not align with improved emissions performance.

This report has also identified information requirements that will assist in the improved estimation of emissions from the WA sheep industry in the future. The most significant of these is the current inability to disaggregate purchased inputs data from ABARES into values that are associated with sheep, cattle and crops. As well as, a formal data source which provides information on the sale weight and age of sheep being transferred inter-state and live exported. The improvements identified will assist in achieving improved accuracy and sensitivity in emissions estimation.

Overall, this study is a significant positive action towards DPIRD's commitment to reducing industry emissions and mitigating climate change. It will also assist DPRID in understanding and identifying current impacts and provides a baseline for assessing future progress in this area, as well as allowing DPIRD to set targets towards reducing GHG emissions.

Recommendations

This study has given some insight into the emission reduction that is possible via the use of anti-methanogenic feed additives and increased flock productivity. Further change is also possible through several other avenues not analysed within this report. To achieve change into the future, the following activities are recommended:

1. Promote the benefits of increased flock productivity from both a profitability and emissions reduction standpoint. This would be assisted by education on the importance and benefits of emission reduction at the farm level.
2. Identify options for collection of improved data to more accurately identify trends in emissions over time, as well as identify the impact of inter-annual variability
3. Supporting research to develop feeding technologies and improved in-field efficacy of anti-methanogenic feed additives.
4. Supporting work on adoption strategies to assist producers to utilise anti-methanogenic feed additives and pastures.
5. Conduct a survey of soil and vegetation management to augment the analysis here with further insight around soil and vegetation carbon changes, and the impact this has on the livestock carbon account.
6. Implementing the carbon neutral strategy at KRF to act as a demonstration site for industry and planning extension and communication activities to maximise the benefit of this activity.
7. Develop industry wide pathways to emission reduction and investigate a broad suite of carbon storage options for different regions and production systems in WA.
8. Aligning analysis presented here with research in the grains sector to maximise benefits from mixed enterprises.
9. To maintain currency and to monitor progress, we recommend updating the analysis on a two-yearly basis to ensure positive (or negative) changes are identified.

References

ABARES. (2021). *Farm Survey Data for Beef, Lamb and Sheep Industries*. All Sheep Industries Combined. http://apps.agriculture.gov.au/mla/

ABS. (2020a). *7121.0 - Agricultural Commodities, Australia.* https://www.abs.gov.au/statistics/industry/agriculture/agricultural-commodities-australia

ABS. (2020b). *7215.0 - Livestock Products, Australia*. https://www.abs.gov.au/statistics/industry/agriculture/livestock-products-australia

AGEIS. (2020). *National Greenhouse Gas Inventory - UNFCC Classifications*. Australian Government - Department of Industry, Science, Energy and Resources. https://ageis.climatechange.gov.au/

AWI. (2019). *Sheep Numbers by State*. https://www.wool.com/market-intelligence/sheep-numbers-by-state/

AWTA. (2021). *AWTA Key Test Data*. https://www.awtawooltesting.com.au/index.php/zh/statistics/key-test-data-new

Commonwealth of Australia. (2020). *National Greenhouse Accounts Factors*. https://publications.industry.gov.au/publications/climate-change/system/files/resources/cf1/national-greenhouse-accounts-factors-august-2019.pdf

Commonwealth of Australia. (2021). *National Inventory Report 2019 Volume 1*. Australian Government, Department of Industry, Energy and Resources.

D.Hubbard. (2021). *DPIRD/Elders Data Discussion 3.12.21*.

Department of Agriculture and Food. (2013). *2021 Sustainability Stra*. Government of Western Australia, Perth, WA.

DPIRD. (2021a). *Sheep Industry Update*.

DPIRD. (2021b, March 2). *The Western Australian Sheep and Wool Industries*. https://www.agric.wa.gov.au/sheep/western-australian-sheep-and-wool-industries

FAO. (2016). *Environmental Performance of Large Ruminant Supply Chains: Guidelines for Assessment*.

Henry, B. K., Butler, D., & Wiedemann, S. (2015). Quantifying Carbon Sequestration on Sheep Grazing Land in Australia for Life Cycle Assessment Studies. *The Rangeland Journal*, *37*(4), 379–388.

ISO. (2006). *ISO 14044:2006 - Environmental Management - Life Cycle Assessment - Requirements and Guidelines*. International Organisation for Standardisation (ISO). https://www.iso.org/standard/38498.html

Meat and Livestock Australia. (2005). *Live Assessment Yard Book - Sheep and Lamb*. http://www.makingmorefromsheep.com.au/_literature_167055/Live_assessment_yardbook.pdf

Myhre, G., Schindell, D., M, B. F., Collins, W., Fugelstvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., & Zhang, H. (2013). Anthroprogenic and Natural Radioactive Forcing. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J.

Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (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.

Pré-Consultants. (2020). *SimaPro 9.1 Software*. Pré-Consultants. https://simapro.com/wp-content/uploads/2020/06/SimaPro91WhatIsNew.pdf

Thomas, D. T., Sanderman, J., Eady, S. J., Masters, D. G., & Sanford, P. (2012). *Whole Farm Net Greenhouse Gas Abatement from Establishing Kikuyu-Based Perennial Pastures in South-Western Australia*. 316–330. https://doi.org/10.3390/ani2030316

Wiedemann, S., Duff, K., Curnow, M., Dolling, P., Bicknell, D., Sanford, P., Collins, J. P., & D'Adhemar, G. (2020). *Katanning Research Facility Carbon Footprint Assessment and Strategy to Achieve Carbon Neutrality by 2030* (Issue December). https://www.agric.wa.gov.au/sites/gateway/files/DPIRD KRF Carbon Footprint CN 2030 Strategy Report 2021.pdf

Wiedemann, S., Ledgard, S., Henry, B., Yan, M., Mao, N., & Russell, S. (2015). Application of Life Cycle Assessment to Sheep Production Systems: Investigating Co-Production of Wool and Meat Using Case Studies from Major Global Producers. *The International Journal of Life Cycle Assessment*, *20*(4), 463–476. https://doi.org/10.1007/s11367-015-0849-z

Wiedemann, S., McGahan, E., Murphy, C., Yan, M.-J., Henry, B., Thoma, G., & Ledgard, S. (2015). Environmental Impacts and Resource Use of Australian Beef and Lamb Exported to the USA Determined Using Life Cycle Assessment. *Journal of Cleaner Production*, *94*, 67–75. https://doi.org/10.1016/j.jclepro.2015.01.073

Wiedemann, S., Yan, M.-J. J., Henry, B. K., & Murphy, C. M. (2016). Resource Use and Greenhouse Gas Emissions from Three Wool Production Regions in Australia. *Journal of Cleaner Production*, *122*, 121–132. https://doi.org/10.1016/j.jclepro.2016.02.025

Wiedemann, S., Yan, M.-J., & Murphy, C. M. (2016). Resource Use and Environmental Impacts from Australian Export Lamb Production: A Life Cycle Assessment. *Animal Production Science*, *56*(7), 1070–1080. https://doi.org/10.1071/AN14647