HFLB GRAIN EMISSION ASSESSMENT

Report

September 2025

pinion
ADVISORY

ABN 87 648 234 975

1300 746 466
hello@pinionadvisory.com
pinionadvisory.com

Office locations

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Authors
Sarah Barrett, Sustainability Lead
James Janakoulis, Sustainability Consultant

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1 Summary

The Hills and Fleurieu Landscape Board (HFLB) in South Australia commissioned Pinion Advisory to quantify of grain emissions totals and intensity (using Scope 1) for a base year (2020/21) and with two emissions reduction scenarios through to 2050. The two emissions reduction projections include an intermediate ambitious and conservative estimate and a best and worst case ambitious and conservative estimate for grain, pulse and forage production in the region.

The overall aim of the project is to assess greenhouse gas (GHG) emissions from grain, pulse and hay and silage production, so the region can begin to measure, review opportunities and act towards reducing emissions.

Table 1 is a summary of the Scope 1 greenhouse gas emissions for cereals, pulses and forage in (HFLB) region, with the second column representing baseline emissions calculated from 2020-21 ABARES data, and columns 3 and 4 representing projected emissions for 2050 with conservative and ambitious emissions reduction targets respectively.

Table 1: Summary of crop emissions (t CO_2-e) across the Hills and Fleurieu Landscape Board Region, 2020-21 baseline and (intermediate) ambitious and conservative projections to 2050.

	Scope 1 Emissions (t CO_2-e)		
Crops	**2020-21 Baseline**	**2050 Conservative**	**2050 Ambitious**
Barley	3,034	2,349	1,413
Oats	269	212	135
Wheat	3,292	2,587	1,603
Other Cereals	30	23	15
Canola	2,171	1,704	1,038
Lentils	71	56	40
Lupins	136	86	35
Other pulses (Beans)	461	358	251
Silage (Forage Crops)	1,922	1,393	707
Hay (Lucerne) – >600ml rainfall	1,025	688	342
Hay (Lucerne) – Irrigated	95	64	32
Hay (Lucerne) – Other	21	14	7
Total	12,527	9,534	5,616

Data disclaimer: crop production, area and yield provided by ABARES 2020-21 for the Hills and Fleurieu Landscape Board region.

2 Methodology

CLASSIFICATION OF SCOPE OF EMISSIONS

GHG emissions are typically categorised into three distinct groups, known as *Scopes,* in line with standard practices used by most emissions calculators. This report focuses on Scope 1 emissions and does not quantify scope 2 or 3 emissions. Scope 1 emissions are those that come directly from activities carried out by a business. These are often called *direct emissions* because they originate from sources the business owns or controls such as the fuel used to power machinery.

2020-21 BASELINE

An initial emissions assessment of the region was made to measure emissions and develop baseline levels.

Crop production data for the region for production year 2020/21, including area (ha) and production (t) was sourced from the ABARES database (ABARES, 2025) (Table 2) for the HFLB region's local government authorities:

- Alexandrina Council
- City of Victor Harbor
- District Council of Yankalilla
- District Council of Mount Barker
- City of Onkaparinga
- Adelaide Hills Council

This information was used to calculate yield data for input into the Grains Greenhouse Gas Accounting Framework (G-GAF) calculator (Version 11.1) (Lopez et al., 2024). The G-GAF calculator was developed by the Primary Industries Climate Challenges Centre (PICCC) to help estimate on-farm emissions across Australia and is consistently updated with nationally determined emissions factors. This calculation did not include sequestration as the HFLB were to apply this separately. Importantly yield was considered stable in this assessment through to 2050.

Table 2: 2020-21 ABARES area (ha) and production (t) of grain crops for the Hills and Fleurieu Landscape Board region.

Category	Crop	Area (ha)	Production (t)	Yield (t/ha)
Cereals	Barley	9,667	33,266	3.44
Cereals	Oats	878	3,291	3.75
Cereals	Other cereals	87	356	4.09
Cereals	Wheat	8,257	33,601	4.07
Cereals	**Sub-total**	**18,889**	**70,514**	**3.73**
Hay and silage	Hay	11,898	53,235	4.47
Hay and silage	Silage	4,158	22,047	5.30
Hay and silage	**Sub-total**	**16,056**	**75,282**	**4.69**
Other crops	Canola	4,435	9,483	2.14
Other crops	Lentils	404	1,174	2.91
Other crops	Lupins	1,396	3,640	2.61

Category	Crop	Area (ha)	Production (t)	Yield (t/ha)
Other crops	Other oilseeds	26	26	1.00
Other crops	Other pulses	2,871	7,487	2.61
Other crops	**Sub-total**	**9,132**	**21,810**	**2.39**
All crops	**Total**	**44,077**	**167,606**	**3.80**

The following are considerations and alterations by Pinion Advisory for improved representation:

- 'Other Cereals' is defined as an average across all cereals.
- 'Other Pulses' is defined as Beans.
- 'Silage' is defined in the G-GAF as Forage Crops.
- 'Hay' is defined as Lucerne hay.

Rainfall above 600ml influences the GAF calculation relating to leaching and runoff. There was 14,844 hectares of land in the region with annual average rainfall above 600mm per year. This area was attributed to fodder (Table 3). Similarly, 990 ha of irrigated land was attributed to fodder crop production (Table 3).

Table 3: Lucerne (Hay) area allocation (ha) in the region.

Crop	>600mm (ha)	Irrigated (ha)	Non-irrigated & <600mm rainfall – Other (ha)	Total (ha)
Forage Crops	4,158			4,158
Lucerne	10,686	990	222	11,898
Total	14,844	990	222	16,056

Utilising client data relevant to the region and agronomic expertise, a typical application of inputs per crop type for the region was estimated (Table 4). This estimate of inputs was then used to estimate emissions using the G-GAF calculator. Lime application was estimated to be 2 tonnes per hectare, across 5 years, per crop, over a third of all cropped lands.

For a more comprehensive breakdown see (Appendix 2).

This provided an output and summary of total emissions including the proportions of methane, nitrous oxide and carbon dioxide, which contribute to total Scope 1 emissions (Table 13).

Table 4: Summary of G-GAF input. Typical application of inputs (per hectare) per crop type for the region

	Barley	Oats	Other Cereals	Wheat	Hay (Lucerne)	Silage (Forage crop)	Canola	Lentils	Lupins	Other pulses	Units
Yield	3.44	3.75	3.75	4.07	4.47	5.30	2.14	2.61	2.61	2.91	tonnes
Area sown	1	1	1	1	1	1	1	1	1	1	ha
Non-Urea Nitrogen Application	20	20	20	20	0	20	30	10	8	8	kg N
Phosphorus Application	16	16	16	16	15	15	15	15	15	15	kg P
Potassium Application	0	0	0	0	30	0	0	0	0	0	kg K
Sulphur Application	10	10	10	10	12.60	5	25	5	5	5	kg S
Urea Application	100	80	110	150	0	65	200	0	0	0	kg Urea
Urea-Ammonium Nitrate (UAN)	4	4	4	4	0	4	4	4	0	0	kg product
Mass of Lime Applied	0.0264	0.0264	0.0264	0.0264	0	0	0.0264	0	0	0	tonnes
Fraction of Lime as limestone vs dolomite	1	1	1	1	1	1	1	1	1	1	Limestone/ dolomite
Annual Diesel Consumption	25	25	25	25	25	25	25	25	25	25	L
Annual Petrol Consumption	1	1	1	1	2	1	1	1	1	1	L
Annual LPG Consumption	0	0	0	0	0	0	0	0	0	0	L

2050 PROJECTIONS

To estimate the potential emissions reduction in the region, three priority interventions were identified through an evaluation of peer-reviewed literature, industry reports and practical expert knowledge. The interventions selected were enhanced efficiency fertilisers, operational efficiency measures and electrification. These were identified as the critical levers for reducing emissions in the region.

The quantum of greenhouse gas reduction from interventions was estimated using two variables, the rate of effectiveness to reduce emissions and the rate of adoption of interventions.

The rates used for effectiveness in reducing Scope 1 emissions is presented in Table 5. A comprehensive justification for these percentages is presented in (Appendix 3).

Table 5: Effectiveness of Scope 1 GHG removal interventions.

	Effectiveness of reduction		
Intervention	**Best-case**	**Intermediate**	**Worst-case**
Enhanced efficiency fertilisers	70% N_2O	45% N_2O	20% N_2O
Operational efficiency	5-10% N_2O 20-30% CO_2	7.5% N_2O 15% CO_2	5% N_2O 20% CO_2
Electrification	98% CO_2	85% CO_2	70% CO_2

The rate of adoption of interventions is shown in Table 6. Adoption rates differ between ambitious and conservative pathways, reflecting the influence of barriers and incentives along the diffusion of innovation adoption curve (Rogers, 2003). Adoption rates were derived using an adoption matrix that considered the barriers and incentives for each intervention (Appendix 1). These factors were weighted using practical industry experience and knowledge of the South Australian agricultural landscape. Adoption projections were modelled over time to 2050 using the ideas from the diffusion of innovation theory (Rogers, 2003), which represents the gradual increase in uptake as technologies mature and farmers gain confidence in their benefits shown in an S-curve.

Table 6: Rate of adoption of interventions

#	Intervention	Scenario	2030 % uptake	2040 % uptake	2050 % uptake
1	Enhanced Efficiency Fertilisers	Ambitious	60	80	95
		Conservative	20	40	60
2	Operational Efficiency	Ambitious	30	60	80
		Conservative	10	20	30
3	Electrification	Ambitious	20	60	80
		Conservative	5	15	40

Two future projections of greenhouse gas emissions have been produced with these estimates of effectiveness and adoption:

(1) The first is the Intermediate projection. Estimates for effectiveness are mid-way between best and worst case scenarios. Adoption rates are taken from Table 6.

(2) The second is the Best and Worst- case scenario projection. This captures the top and bottom of the expected range of intervention effectiveness. Adoption rates are also taken from Table 6.

INTERMEDIATE SCENARIO

In this scenario, the effectiveness of reduction is the midpoint between the best and worst case estimates in Table 8 and 9. This effectiveness percentages are applied consistently across both rates of adoption (ambitious and conservative) for each projection year (2030, 2040 and 2050) (Table 7).

This design allows the intermediate projection to capture a midway outcome without assuming either the upper or lower range of effectiveness, and it provides a practical reference case that aligns with the most likely trajectory of industry practice to 2050.

By combining a constant midpoint effectiveness rate with variable adoption rates, the intermediate scenario provides a balanced case against the more extreme assumptions of the best- and worst-case projections. This ensures that the analysis captures a more realistic pathway.

Table 7: Intermediate scenario for three emissions reduction interventions

#	Intervention	Scenario	2030		2040		2050	
			% reduction	% uptake	% reduction	% uptake	% reduction	% uptake
1	Enhanced Efficiency Fertilisers	Ambitious	45	60	50	80	55	95
		Conservative	45	20	50	40	55	60
2	Operational Efficiency	Ambitious	15	30	20	60	25	80
		Conservative	15	10	20	20	25	30
3	Electrification	Ambitious	85	20	85	60	90	80
		Conservative	85	5	85	15	90	40

The outcomes from the analysis of the intermediate scenario are an ambitious projection (with high adoption) and a conservative projection (with lower adoption).

BEST AND WORST CASE SCENARIO

Two scenarios were developed to capture the full uncertainty range of intervention performance (Table 8 and Table 9).

The best-case represents the upper level of intervention effectiveness and ambitious rates of technology adoption (high in both parameters).

The worst-case represents the lower level of intervention effectiveness and a conservative rate of technology adoption (low in both parameters).

Table 8: Best case

#	Intervention	Scenario	2030		2040		2050	
			% reduction	% uptake	% reduction	% uptake	% reduction	% uptake
1	Enhanced Efficiency Fertilisers	Ambitious	70	60	75	80	80	95
2	Operational Efficiency	Ambitious	20	30	25	60	30	80
3	Electrification	Ambitious	98	20	98	60	98	80

Table 9: Worst case

#	Intervention	Scenario	2030		2040		2050	
			% reduction	% uptake	% reduction	% uptake	% reduction	% uptake
1	Enhanced Efficiency Fertilisers	Conservative	20	20	25	40	30	60
2	Operational Efficiency	Conservative	10	10	15	20	20	30
3	Electrification	Conservative	70	5	75	15	80	40

The outcomes from this analysis will be boundaries for the scenarios to 2050 with most emissions reduction and least emissions reduction.

3 Results

TOTAL GREENHOUSE GAS EMISSIONS FOR BASELINE YEAR (2020-21)

The total Scope 1 emissions for the region for 2020-21 was 12,527 t CO2-e (Table 10). The greatest input or activity that contributed to total emissions, was fertiliser (N_2O), closely followed by fuel (CO_2).

Table 10: Total emissions for the region's 2020-21 baseline.

Scope 1 emissions	Total Emissions (t CO_2-e)
CO_2 - Fuel	3,102
CO_2 - Lime	244
CO_2 - Urea	2,557
CH_4 - Field Burning	-
CH_4 - Fuel	3
N_2O - Fertiliser	3,175
N_2O - Atmospheric Deposition	349
N_2O - Field Burning	-
N_2O - Crop Residues	2,708
N_2O - Leaching and Runoff	374
N_2O - Fuel	15
Total	12,527

The emissions profile of the cropping system is dominated by nitrous oxide (N_2O) and carbon dioxide (CO_2) sources. Proportionally, N_2O driven by emissions related to fertiliser application accounts for the largest single share at 25% of total emissions, followed closely by CO_2 from on-farm fuel use (25%) and N_2O from crop residues (22%) (Figure 1). CO_2 emissions from urea application contribute 20% of total emissions, while CO_2 from lime contributes 2%. The assessment of lime on farm was measured at a 2 tonne per hectare basis, per crop, over a 5-year application cycle, at only a third of the cropped area, equating to 0.0264 (t/ha/year/crop/33%). Other minor contributions are negligible.

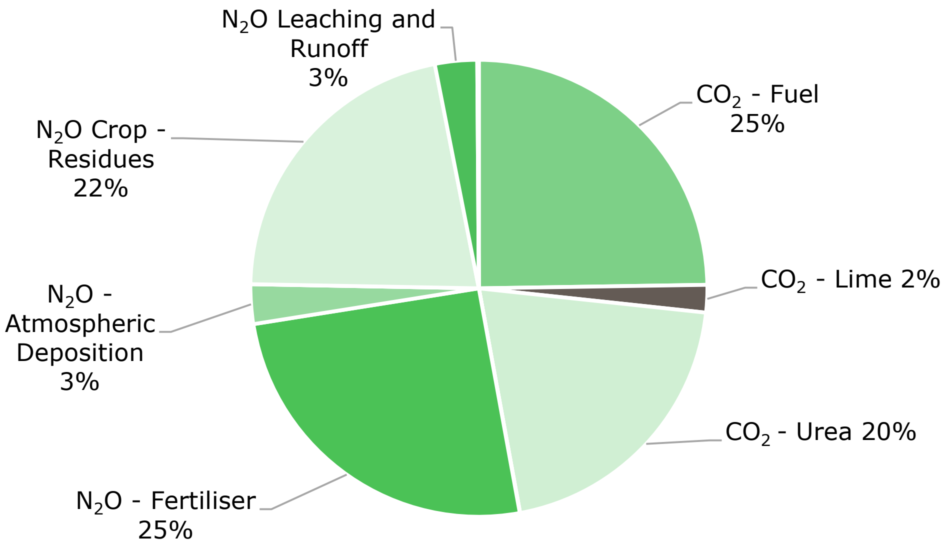


Figure 1: Emission proportion per input for the region, showing >1% contributions.

FORECASTING TO 2050: INTERMEDIATE SCENARIO

Under the intermediate projection, total Scope 1 emissions are forecast to decline from 12,527 in 2020 to 5,616 (t CO_2-e) in 2050 for the ambitious adoption pathway, and to 9,534 t CO_2-e in 2050 for the conservative adoption pathway (Figure 2). Emissions decline in both situations due to forecast improvements in technology and adoption over time.

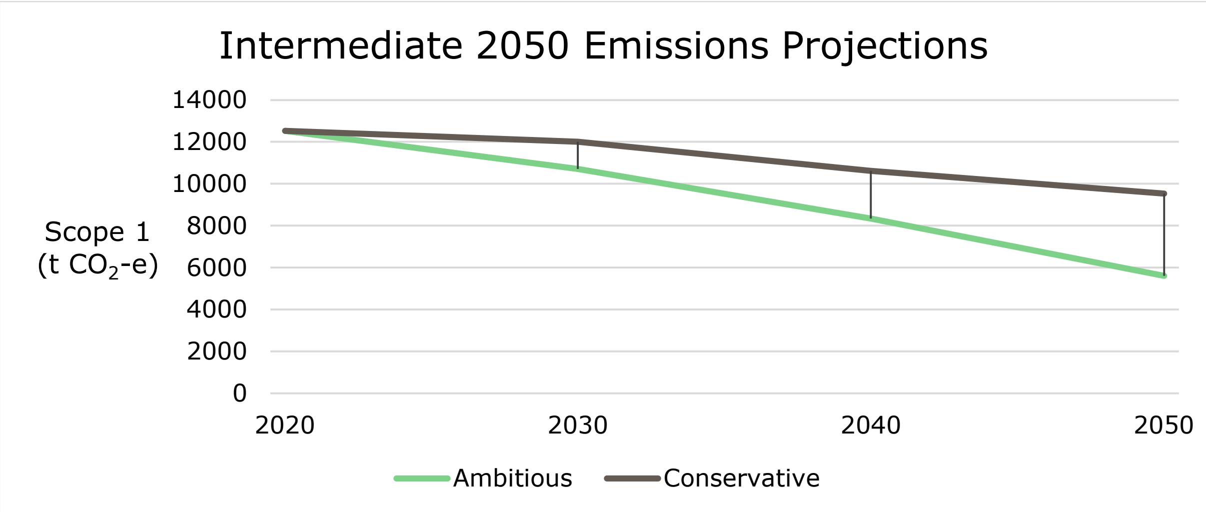


Figure 2: Scope 1 emissions (2020–2050): Illustrating intermediate trajectories for Scope 1 emissions (measured in tonnes of CO_2-e per tonne of crop).

By 2050, the main sources of emissions are CO_2 from urea (2,045–2,365 t CO_2-e), N_2O from fertiliser (276–1,967 t CO_2-e) and N_2O from crop residues (2,708 t CO_2-e). Crop residues remained consistent over the years, as this is not influenced by any of the interventions. Other categories, including CO_2 from fuel, CO_2 from lime and N_2O from atmospheric deposition and leaching, remain smaller contributors across both ambitious and conservative projections.

The difference in total Scope 1 emissions between the ambitious and conservative intermediate projections in 2050 is 3,918 t CO_2-e (Table 11). The largest differences occur in N_2O from fertiliser (−1,691 t CO_2-e), CO_2 from fuel (−1,469 t CO_2-e), and N_2O from leaching and runoff (−214 t CO_2-e). Smaller differences are observed for CO_2 from lime (−31 t CO_2-e), N_2O from atmospheric deposition (−186 t CO_2-e) and CO_2 from urea (−320 t CO_2-e).

Table 11: Intermediate projection: 2050 total emissions (t CO_2-e) for both ambitious and conservative estimates.

	2020-21 (t CO_2-e)	**Intermediate Total Scope 1 emissions 2050 (t CO_2-e)**	
Output	**Baseline Year Emissions**	**Conservative**	**Ambitious**
CO_2 - Fuel	3,102	1,749	280
CO_2 - Lime	244	226	195
CO_2 - Urea	2,557	2,365	2,045
CH_4 - Field Burning	-	-	-
CH_4 - Fuel	3	1	-
N_2O - Fertiliser	3,175	1,967	276
N_2O - Atmospheric Deposition	349	216	30
N_2O - Field Burning	-	-	-
N_2O - Crop Residues	2,708	2,708	2,708
N_2O - Leaching and Runoff	374	292	79
N_2O - Fuel	15	9	1
Scope 1 Total	12,527	9,534	5,616

When compared with the baseline, the intermediate ambitious scenario delivered the largest emissions reduction through electrification (24.3%), with additional reductions from enhanced efficiency fertilisers (16.5%) and operational efficiency (14.5%). In contrast, the intermediate conservative scenario achieved smaller reductions: electrification (10.6%), enhanced efficiency fertilisers (9.5%) and operational efficiency (3.8%) (Table 12).

Table 12. Emission reduction opportunities for grain under intermediate ambitious and conservative projections

	Ambitious	Conservative
Enhanced Efficiency Fertiliser	16.5%	9.5%
Operational Efficiency	14.5%	3.8%
Electrification	24.3%	10.6%

Table 13: Summary of Scope 1 (t CO_2-e) emissions per greenhouse gas across crops in the region, Intermediate scenario

	t CO_2-e												
	Barley	**Oats**	**Wheat**	**Other Cereals**	**Canola**	**Lentils**	**Lupins**	**Beans**	**Forage Crops (Silage)**	**Hay (Lucerne) - >600ml rainfall**	**Hay (Lucerne) - Irrigated Crop**	**Hay (Lucerne) - Non irrigated & <600ml rainfall**	**Total (t CO_2-e)**
CO_2 - Fuel	674	61	576	6	311	28	97	200	290	770	71	16	3,102
CO_2 - Lime	101	9	86	1	47	0	0	0	0	0	0	0	244
CO_2 - Urea	719	52	917	7	659	0	0	0	202	0	0	0	2,557
CH_4 - Field Burning	0	0	0	0	0	0	0	0	0	0	0	0	-
CH_4 - Fuel	1	0	0	0	0	0	0	0	0	1	0	0	3
N_2O - Fertiliser	785	62	900	8	664	6	13	28	709	0	0	0	3,175
N_2O - Atmospheric Deposition	86	7	99	1	73	1	1	3	78	0	0	0	349
N_2O - Field Burning	0	0	0	0	0	0	0	0	0	0	0	0	-
N_2O - Crop Residues	664	78	710	7	416	36	23	228	267	251	23	5	2,708
N_2O - Leaching and Runoff	0	0	0	0	0	0	0	0	374	0	0	0	374
N_2O - Fuel	3	0	3	0	2	0	0	1	1	4	0	0	15
Scope 1 Total	**3034**	**269**	**3292**	**30**	**2171**	**71**	**136**	**461**	**1922**	**1025**	**95**	**21**	**12,527**

FORECASTING TO 2050: BEST AND WORST CASE SCENARIO

Figure 3 demonstrates the case where there are maximum intervention effectiveness and maximum adoption (best case) and lowest intervention effectiveness and lowest adoption (worst case). The total difference between these best and worst cases for Scope 1 emissions was 5,112 t CO_2-e (Table 14). The focal contributor to this difference was the ambitious reductions in Scope 1 emissions from the complete removal of CO_2 fuel emissions and a considerable reduction in N_2O fertiliser, atmospheric decomposition and leaching and runoff emissions.

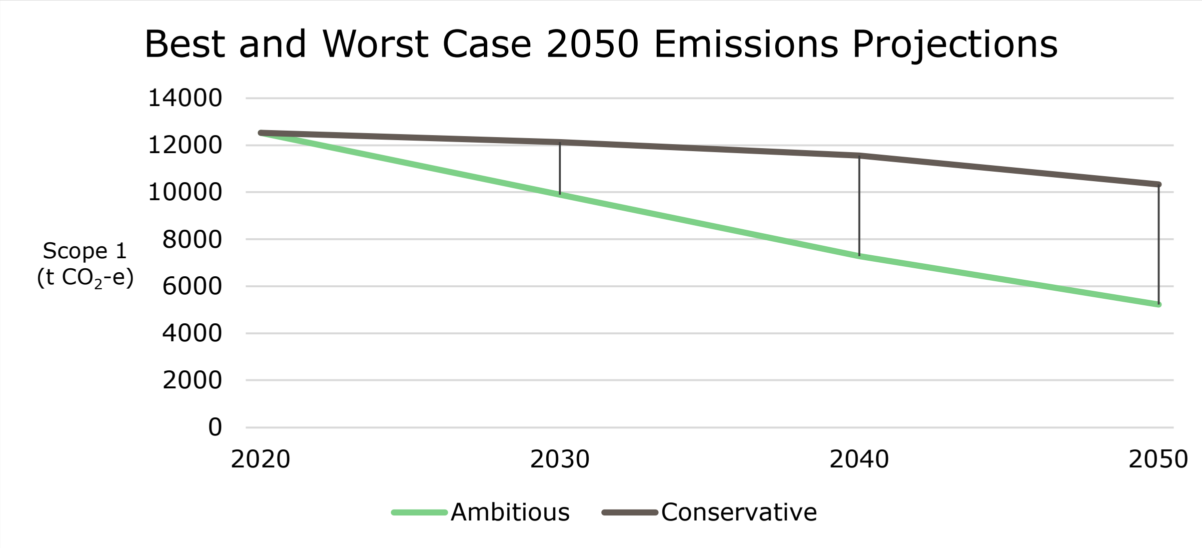
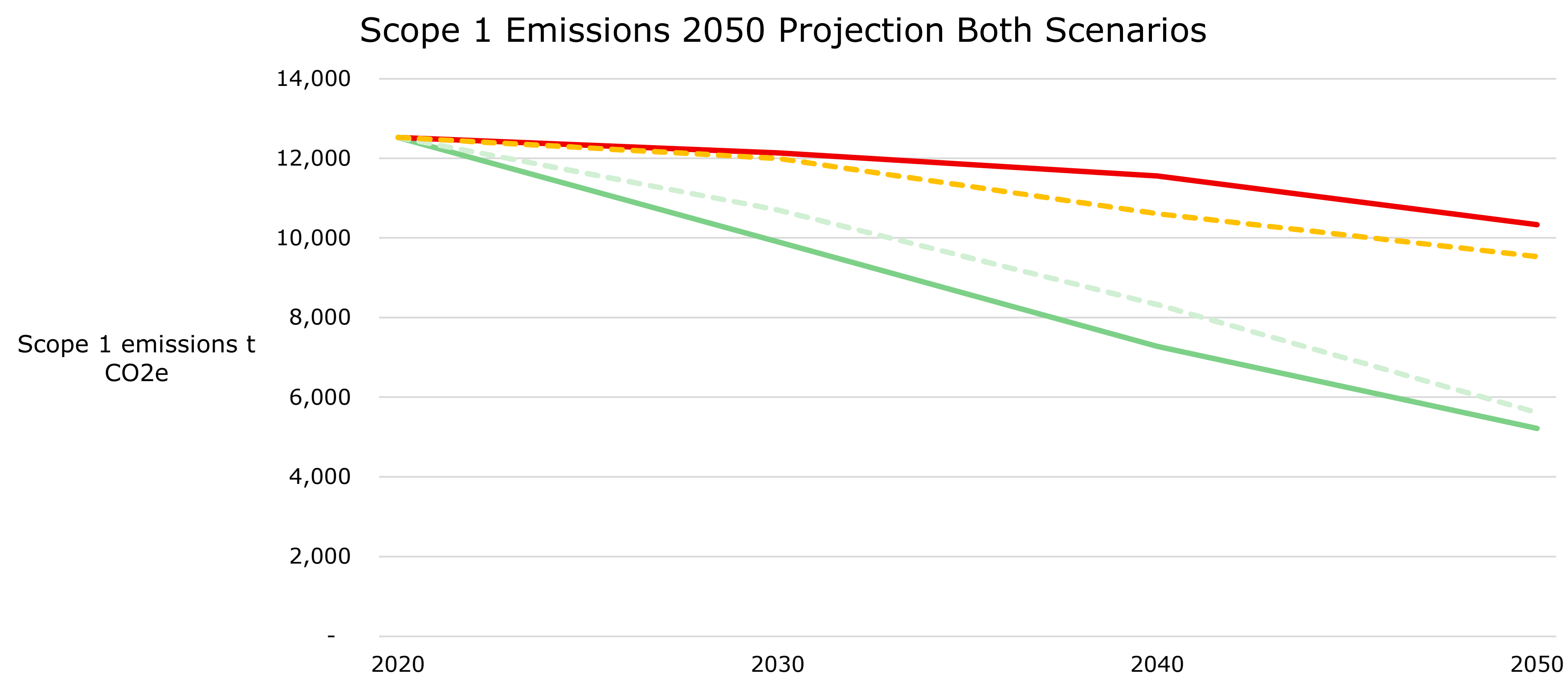


Figure 3: Scope 1 emissions (2020–2050): Illustrating best and worst case trajectories for Scope 1 emissions (measured in tonnes of CO_2-e per tonne of crop) for the Hills and Fleurieu Landscape Board region.

Table 14: Baseline comparison to worst-case and best-case estimates of Scope 1 emissions across G-GAF (v11.1) outputs.

	2020-21 (t CO_2-e)	2050 (t CO_2-e)	
Output	**Baseline Year Emissions**	**Worst-Case**	**Best-Case**
CO_2 - Fuel	3,102	1,917	-
CO_2 - Lime	244	229	186
CO_2 - Urea	2,557	2,410	1,968
CH_4 - Field Burning	-	-	-
CH_4 - Fuel	3	2	-
N_2O - Fertiliser	3,175	2,484	251
N_2O - Atmospheric Deposition	349	273	28
N_2O - Field Burning	-	-	-
N_2O - Crop Residues	2,708	2,708	2,708
N_2O - Leaching and Runoff	374	301	83
N_2O - Fuel	15	9	-
Total	12,527	10,335	5,223



	2020	2030	2040	2050
Best	12,527	9,900	7,279	5,223
Worst	12,527	12,132	11,552	10,335
Ambitious Intermediate	12,527	10,704	8,331	5,616
Conservative Intermediate	12527	12000	10608	9534

Figure 4. Scope 1 Emissions 2050 Projection for both best (highest effectiveness and highest adoption) and worst (weakest effectiveness and weakest adoption) case scenarios and the intermediate ambitious and conservative projections.

4 Discussion

2020-21 BASELINE

The HFLB region's cropping area accounts for 1% of the cropped area in South Australia (ABARES, 2025) and accordingly, has a low emissions output of 12,527 t CO_2-e (Table 7). The region's Scope 1 emissions intensity for grain is 74.74 kg of CO_2-e per tonne of grain, which is markedly lower than the 2005 national average of 189 kg of CO_2-e per tonne of grain produced (CSIRO, 2022). These metrics do not account for scope 2 or 3 emissions. This reflects the low direct on-farm emissions in the region.

Comparable to other Australia-wide data sets and industry norms (GRDC, 2025; GRDC, 2023; CEFC, 2022; Bell, 2024), our results indicate that 53% of Scope 1 emissions are directly related to the use of fertilisers. Urea influences both CO_2 and N_2O through hydrolysis and nitrification respectively, in which case fertilisers account for 73% of total Scope 1 emissions.

The other major source of Scope 1 emissions in the region for cropping is fuel (25%). This ratio is consistent with other greenhouse gas emissions assessments on Scope 1 emissions across agricultural industries (Bell et a., 2024; GRDC & CSIRO, 2023; GRDC, 2025).

The baseline results indicate that direct N_2O emissions from nitrogen inputs and indirect CO_2 emissions from fuel and fertiliser use are the primary drivers of the region's greenhouse gas footprint, highlighting these as intervention points for mitigation strategies.

2050 PROJECTIONS

The two projections considered were:

(1) An intermediate scenario with medium reductions in effectiveness and ambitious and conservative rates of adoption.

(2) A best and worst case scenario with high effectiveness and ambitious adoption (best) compared to lowest effectiveness and conservative adoption (worst).

The comparison between the current baseline and the 2050 projections provides a snapshot of potential changes in emissions from cropping in the region (Table 14 and Figure 4).

Table 15. Total Emissions results from the baseline, in comparison to each projection

Emissions by 2050	Baseline	Worst	Intermediate conservative adoption	Intermediate ambitious adoption	Best
GHG emissions (t CO_2-e)	12,527	10,335	9,534	5,616	5,223

To calculate these projections, three interventions were considered: enhanced efficiency fertilisers, operational efficiency and electrification. These interventions were identified from a combination of industry publications, the most up-to-date research and practical advice from experienced industry professionals. Each intervention represents a group of measures under a common theme.

The intermediate scenario forms the focal point of this report. It represents a balanced pathway, assuming consistent medium reductions in effectiveness across all three interventions and different adoption rates across an ambitious and conservative projection. This projection provides a reasonable reference case for the industry's likely trajectory if current trends in technology and adoption continue. In contrast, the best and worst case projections set the boundaries of potential change, with ambitious projections reflecting the upper end of reductions and uptake and conservative projections reflecting the lower end.

The efficacy of each intervention was expressed as a percentage reduction in emissions, with ambitious and conservative projections varying over time. While it is possible to assume that effectiveness remains constant and only adoption changes, this analysis reflects an expectation that effectiveness will improve as technologies develop, regulations evolve and markets create stronger incentives.

Adoption was modelled through an adoption matrix (Appendix 1), which considered barriers and incentives that influence uptake of farming practices and technology associated with each intervention. Adoption rates are projected to increase over time, with the Diffusion of Innovations theory (Everett Rogers, 2003) used to match the matrix rating with the stage of adoption, i.e. innovators, early adopters, early majority, late majority and laggards (Table 16). Progression through these stages has been determined with consideration of improvement in production outcomes associated with new technologies. As fertilisers, machinery and management practices become more reliable, efficient and profitable, adoption becomes more attractive to growers. Support from extension services, industry promotion and financial incentives further accelerates uptake, while the absence of such support, or limited access to technologies, can slow progress.

Table 16. Diffusion of Innovation progression of uptake utilised to map low and high adoption rates

Rating	Adoption	
(red)	0-2.5%	Innovators
(orange)	2.5 – 16%	Early adopters
(yellow)	16-50%	Early majority
(light green)	50-84%	Late majority
(green)	84-100%	Laggards

We acknowledge that with any future projection there is informed speculation and inferencing and therefore, maintain that these estimations are not static.

ENHANCED EFFICIENCY FERTILISERS

Enhanced efficiency fertilisers (EEFs) include nitrification inhibitors (NIs), urease inhibitors (UIs) and coated or controlled-release fertilisers (CRFs). These products are designed to improve nitrogen use efficiency by slowing different steps in the nitrogen cycle, which can reduce nitrogen losses and associated nitrous oxide (N_2O) emissions from fertiliser use. Each of these technologies has its own expected reduction rate, but their effectiveness varies widely across different soils, climates and management systems. Accordingly, assumptions around the performance and adoption in South Australian cropping regions is context specific. We anticipate NIs would be the most utilised EEF matching the climate of the region. Our research indicated that the effectiveness reduction for EEFs was 20-70% and adoption rates varied depending on the scenario and the year. In the region, the projected ambitious use of enhanced efficiency fertiliser to 2050 results indicate an overall reduction from the 2020-21 baseline emissions of 54% in N_2O emissions in 2050. Alternatively, the projected conservative use had a reduction of 22% in N_2O emissions. It's important to note that EEFs do not impact crop residues, which equated to 23% of N_2O emissions in the baseline year.

Nitrification inhibitors (NIs) offer a well-documented pathway to reduce nitrous oxide (N_2O) emissions from fertiliser use and their use has been widely studied as a mitigation strategy in agricultural systems. Lam et al. (2017) demonstrated that NIs can reduce N_2O emissions by an average of around 50% across a broad range of soil types and climates, primarily by slowing the microbial conversion of ammonium to nitrate and therefore, reducing the pool of nitrate available for denitrification. While the authors note that effectiveness is influenced by soil conditions, temperature and moisture, and that there is potential for trade-offs such as increased ammonia volatilisation, the evidence shows they consistently lower direct N_2O emissions under certain conditions. This provides a strong empirical basis for applying the reported reduction rates from this study, as a proxy in estimating the potential N_2O abatement from nitrification inhibitor adoption in the region's cropping systems.

Suter et al. (2016) investigated the use of enhanced efficiency fertilisers (EEFs) in temperate Australian conditions and found that nitrification inhibitors can substantially reduce nitrous oxide (N_2O) emissions from fertiliser. In a field trial on ryegrass, the nitrification inhibitor DMPP reduced fertiliser-induced N_2O emissions by 76% compared with standard urea, mainly by suppressing nitrate formation and limiting the substrate available for denitrification. This reduction occurred across autumn, winter and spring. These findings provide a robust evidence base for using the reported 20-70% per cent reduction as a reasonable proxy estimate for the potential mitigation of N_2O emissions from nitrification inhibitor use in South Australian cropping systems.

Performance is strongly shaped by local soils, climate and crop management. Yield benefits from all EEFs are inconsistent and often absent, particularly in systems with high background nitrogen levels, such as paddocks following legumes, or where fertiliser use has been historically high (PICCC, 2021a). This limits their economic appeal, as adoption decisions in cropping systems are driven largely by expected returns (PICCC, 2021b). Consequently, assumptions about adoption rates are closely linked to assumptions about performance. This influenced our attribution of a high adoption rate in the ambitious scenario and a low adoption rate in the conservative scenario. Farmers are unlikely to use these products where there is low emissions reduction effectiveness, and they will not be adopted widely without reliable yield benefits.

Yield increases are only part of the attraction for adoption. Growers are also motivated by cost efficiencies. If EEFs reduce the proportion of nitrogen fertiliser lost to the atmosphere, then the value of every tonne applied increases. For example, if an EEF reduces nitrogen losses by 50% but costs 25% more than conventional urea, the overall saving in prevented losses outweighs the higher purchase price. This makes the product financially attractive, while also lowering emissions, creating a stronger incentive for adoption than yield benefits alone.

This result demonstrates that targeting fertiliser use remains a key step towards reducing Australia's agricultural industry's emissions inventories. However, as yield is directly related to nitrogen fertiliser application rates and quantity in Australia (Hochman et al., 2013), there is unlikely to be a reduction in fertiliser use because of this reliance, and more so a demand for new technologies or products to target the processes within the nitrogen and carbon cycle to mitigate emissions. Adoption is therefore likely to be strongest where EEFs can deliver both economic benefits and environmental outcomes, reinforcing that cost-efficiency may be as critical to uptake as yield benefits.

OPERATIONAL EFFICIENCY

Operational efficiencies include optimisation of inputs, precision agriculture techniques such as variable rate input application, and practices aimed at addressing yield gaps. Collectively, these measures target both fertiliser and fuel use, which are key contributors to Scope 1 emissions in cropping systems.

Modelling of yield response to nitrogen use efficiency (NUE) and water-limited yield potential (WYLP) demonstrates that optimising fertiliser application can reduce both emissions intensity (emissions per tonne of grain produced) and absolute emissions when market effects are considered (Simmons et al., 2020). As NUE improves, greater yield gains are achieved per unit of fertiliser applied, which lowers emissions intensity. By contrast, systems that restrict nitrogen inputs simply to reduce absolute emissions may unintentionally increase emissions intensity per unit of grain, due to yield penalties.

The key source of Scope 1 emissions for grain producers is fertiliser application, through processes including volatilisation, denitrification and leaching. Yields of Australian wheat production are strongly limited by nitrogen fertiliser supply (Hochman et al., 2013), and research shows that applying higher rates of nitrogen generally increases total emissions from wheat systems (Ali et al., 2017; Huang et al., 2017). This highlights the importance of improving efficiency rather than reducing inputs indiscriminately.

Many of these operational practices act directly on the nitrogen cycle, for example, delaying fertiliser release ensures that nitrogen availability is better synchronised with crop demand, lowering the risk of losses to the atmosphere or groundwater, with research showing reductions in nitrogen loss of 35–52% (Wallace, 2022). Similarly, deep placement of nitrogen fertiliser reduces exposure of urea to surface conditions, significantly limiting ammonia volatilisation and achieving reductions of up to 82% (Govindasamy et al., 2023).

Precision agriculture approaches, including integrated nutrient management and variable rate fertiliser application, work by matching fertiliser inputs more accurately to spatial and temporal crop requirements. This reduces the size of nitrate pools in the soil and therefore, the substrate available for denitrification, with evidence pointing to reductions in emissions of 15–30% (Wang et al., 2025) and 13–44% (GrainGrowers, 2022). Other supporting practices target indirect nitrogen losses. Controlled Traffic Farming (CTF) and improved machinery efficiency lower fuel use and energy-related emissions by around 15% each, while strategic lime application can stabilise soil pH and suppress N_2O formation, leading to reductions of around 19% (GrainGrowers, 2022).

Taken together, these findings provide the evidence base for the range of effectiveness values applied to operational efficiency in this analysis, forming the foundation of the ambitious and conservative projections modelled. By drawing from established research across fertiliser management, precision agriculture and fuel efficiency measures, the projected reductions reflect both the potential for significant abatement and the variability in outcomes across farming systems.

ELECTRIFICATION

Fuel use accounts for approximately 25% of total on-farm greenhouse gas emissions in grain production in the region, making it a meaningful contributor to overall emissions profiles. Fuel is a significant cost in crop production, suggesting that it may be the strongest target for emissions reduction (low hanging fruit) through electrification. Exploring renewable energy alternatives, electric machinery, or biofuel compatible equipment, presents a potential win–win opportunity reducing both emissions and longterm operating costs (Chel and Kaushik, 2011). However, the absence of accessible alternatives, cost of transition and practical application is currently limiting. As technology advances and more equipment options become available, transitioning to renewable energy sources may offer both economic and environmental benefits for grain growers.

Early opportunities for electrification in agriculture lie with fixed or semi-fixed loads such as irrigation pumps, aeration systems and other stationary equipment, where proven technologies like solar, variable speed drives and battery storage can already be applied with relatively low disruption (CEFC, 2019). These applications are easier to integrate because they are predictable, energy-intensive and can often be scheduled to match renewable supply. The next stage of adoption will focus on mobile equipment, with higher horsepower tractors, harvesters and field machinery expected to transition as commercial electric models become available and charging infrastructure becomes more routine on farms (CEFC, 2019). This staged trajectory underpins the adoption rates used in our projections, with increasing equipment availability and improving production outcomes identified as the key triggers for more rapid uptake over time.

ASSUMPTIONS AND JUSTIFICATIONS

The projected rates of adoption explored were informed directly by the adoption matrices developed for each intervention (Appendix 1). These matrices capture the balance between incentives and barriers over time and provide a structured method for translating qualitative insights from industry, literature and expert experience into percentage adoption rates.

The adoption trajectories follow the Diffusion of Innovations theory (S-curve). The S-curve describes how adoption typically begins slowly, with only a small number of early adopters willing to take on cost and risk. As barriers reduce and incentives strengthen, uptake enters a rapid growth phase, where adoption expands across the majority of users. Finally, adoption slows again as the technology reaches maturity and the remaining farmers either have no incentive to change or face barriers that outweigh the benefits. In this way, the S-curve captures both the time lag and the acceleration that characterise how agricultural technologies become embedded within an industry.

In 2020–21, uptake of treated fertilisers faced strong barriers. Limited product availability, high cost and a lack of demonstrated yield improvement meant there was no clear incentive for adoption. This is reflected in very low early uptake rates. By 2030, however, modest adoption is anticipated as costs begin to fall and reductions in nitrogen losses become more evident. By 2040 and 2050, as the cost of treated fertilisers decreases further and efficacy becomes well established in local conditions, the practice transitions towards mainstream adoption. This progression underpins the increasing uptake percentages in Table 7, rising to 95% under the ambitious scenario by 2050.

Electrification of on-farm equipment faces the highest initial barriers due to capital cost and system change requirements. In 2020, major financial outlays for machinery replacement restricted uptake. By 2030, financial incentives and early examples of transition begin to lower these barriers, though adoption remains limited. By 2040, cost savings from fuel substitution and reductions in maintenance expenses improve the financial case, resulting in accelerated uptake. By 2050, electrification becomes increasingly competitive as new equipment becomes the industry norm. This trajectory is reflected in the adoption percentages of Table 7, with uptake climbing more slowly in the conservative pathway but reaching 80% in the ambitious pathway by 2050.

Operational efficiency measures, such as digital mapping, precision agriculture and improved input management, faced early barriers linked to high equipment costs, the need for new skills and the scale of operations required to justify investment. In 2020, these barriers were dominant, restricting adoption. By 2030, production gains begin to offset costs, though access to technology and training remain barriers for some farmers. By 2040 and 2050, cost barriers continue to ease as new efficiencies are demonstrated and become embedded in mainstream farming practice. This is captured in Table 7 by adoption rates rising from 30% in 2030 to 80% by 2050 under the ambitious projection.

5 Conclusion

This analysis highlights that while the Hills and Fleurieu Landscape Board region contributes only a small share of South Australia's cropped emissions, the structure of its emissions profile is consistent with national trends, with fertiliser and fuel use dominating Scope 1 outputs. The projections to 2050 show that meaningful reductions are possible, but outcomes depend heavily on both the effectiveness of available technologies and the rates of their adoption. Enhanced efficiency fertilisers, operational efficiency measures and electrification each offer substantial abatement potential; however, their uptake is shaped by context-specific barriers, incentives and evolving economics. The adoption matrices and the Diffusion of Innovation S-curve framework illustrate how technologies initially face slow uptake due to social barriers, but accelerate once confidence, accessibility and profitability improve. By situating the intermediate projection as the reference pathway, and using best and worst scenarios as bounds, this report provides a structured picture of the likely trajectory of emissions in the region. Ultimately, achieving significant reductions will rely on aligning technological development with farmer decision-making, ensuring that interventions are both effective in reducing emissions and viable in practice for grain producers in the region.

Appendix 1. Adoption Matrix

Enhanced Efficiency Fertiliser

		Barriers			
Incentives	**Incentives**	**Insignificant:** no net influence on cost of production; very minor implementation barriers; immediate realisation of outcome from implementation	**Minor:** small cost or mild access issue	**Moderate:** costs impact on cost of production; access issues; require education, new skills; equipment upgrades or outsourcing.	**Major:** Major budgeted costs requiring finance; requires purchase of new equipment; major investment; yield penalty
	Insignificant: no recognisable incentive. Values driven, non-financial			**2020/21** No recognisable incentive for improvement of yield. Access issues with limited products on the market. Incentive for emissions reduction without a production outcome unpalatable.	
	Minor: Limited and unreliable financial incentives				
	Moderate: Financial or production gain to cover cost of implementation		**2030** Small cost barrier Incentive moving to well substantiated impact on production through reduction in N losses.		
	Major: Immediate and increasing production and/or financial gain covers barrier costs/income penalties.	**2040 and 2050** Market forces drive cost down in respect to cost of production. N availability and efficacy is well established in local conditions. Becomes best practice.			

Operational Efficiency

		Barriers			
Incentives	**Incentives**	**Insignificant:** no net influence on cost of production; very minor implementation barriers; immediate realisation of outcome from implementation	**Minor:** small cost or mild access issue	**Moderate:** costs impact on cost of production; access issues; require education, new skills; equipment upgrades or outsourcing.	**Major:** Major budgeted costs requiring finance; requires purchase of new equipment; major investment; yield penalty
	Insignificant: no recognisable incentive. Values driven, non-financial			**2020** Digital mapping costs Technology uptake barriers include investment required in purchase of variable rate machinery or outsourcing to contractors. New skill development required. Scale of operations a barrier to investment in capital	
	Minor: Limited and unreliable financial incentives				
	Moderate: Financial or production gain to cover cost of implementation		**2040** Cost barriers ease	**2030** Cost barriers remain however production gains realised	
	Major: Immediate and increasing production and/or financial gain covers barrier costs/income penalties.		**2050** Cost barrier easing along with ongoing realisation of production and financial gains. New efficiencies found.		

Electrification

		Barriers			
Incentives	**Incentives**	**Insignificant:** no net influence on cost of production; very minor implementation barriers; immediate realisation of outcome from implementation	**Minor:** small cost or mild access issue	**Moderate:** costs impact on cost of production; access issues; require education, new skills; equipment upgrades or outsourcing.	**Major:** Major budgeted costs requiring finance; requires purchase of new equipment; major investment; yield penalty
	Insignificant: no recognisable incentive. Values driven, non-financial				**2020** Purchase of new machinery costly; adaptation of system major physiological barrier
	Minor: Limited and unreliable financial incentives				
	Moderate: Financial or production gain to cover cost of implementation			**2040** Mainstream adoption with financial gains realised and cost of transition for new equipment decreasing.	**2030** Capital constraints remain however, financial incentives for transition begin to take shape. Financial gain becomes more compelling
	Major: Immediate and increasing production and/or financial gain covers barrier costs/income penalties.				

Appendix 2. G-GAF Outputs

Crop	Barley	Oats	Wheat	Other Cereals	*Canola* Oilseeds		Summary of Scope 1	t CO_2e/farm	
Outputs	**t CO_2e/farm**	**t CO_2e/farm**	**t CO_2e/farm**	**t CO_2e/farm**	**t CO_2e/farm**	**total t CO_2e/farm**			**total proportion of Scope 1 emissions**
CO_2 - Fuel	0.0698	0.0698	0.0698	0.0698	0.0698	0.35	CO_2	0.8755	19%
CO_2 - Lime	0.0105	0.0105	0.0105	0.0105	0.0105	0.05	CH_4	0.0003	3%
CO_2 - Urea	0.0744	0.0597	0.1110	0.0817	0.1477	0.47	N_2O	0.9732	26%
CH_4 - Field burning	0.0000	0.0000	0.0000	0.0000	0.0000	0.00			0%
CH_4 - Fuel	0.0001	0.0001	0.0001	0.0001	0.0001	0.00			0%
N_2O - Fertiliser	0.0813	0.0701	0.1090	0.0868	0.1489	0.50			27%
N_2O - Atmospheric Deposition	0.0089	0.0077	0.0120	0.0095	0.0164	0.05			3%
N_2O - Field Burning	0.0000	0.0000	0.0000	0.0000	0.0000	0.00			0%
N_2O - Crop Residues	0.0686	0.0887	0.0860	0.0842	0.0932	0.42			23%
N_2O - Leaching and Runoff	0.0000	0.0000	0.0000	0.0000	0.0000	0.00			0%
N_2O - Fuel	0.0003	0.0003	0.0003	0.0003	0.0003	0.00			0%
Scope 1 Total	**0.3138**	**0.3069**	**0.3986**	**0.3429**	**0.4867**	**1.8490**			

Crop	*Lupins* Other legume	*Beans* Pulses	Forage Crops	*Lentils* Pulses		Summary of Scope 1	t CO_2e/farm	
Outputs	**t CO_2e/farm**	**t CO_2e/farm**	**t CO_2e/farm**	**t CO_2e/farm**	**Total t CO_2e/farm**			**total proportion of Scope 1 emissions**
CO_2 - Fuel	0.0698	0.0698	0.0698	0.0698	0.3	CO_2	0.4008	41%
CO_2 - Lime	0.0000	0.0000	0.0000	0.0000	0.0	CH_4	0.0003	0%
CO_2 - Urea	0.0000	0.0000	0.0487	0.0010	0.0	N_2O	0.3795	7%
CH_4 - Field burning	0.0000	0.0000	0.0000	0.0000	0.0			0%
CH_4 - Fuel	0.0001	0.0001	0.0001	0.0001	0.000			0%
N_2O - Fertiliser	0.0097	0.0097	0.0618	0.0136	0.1			14%
N_2O - Atmospheric Deposition	0.0011	0.0011	0.0068	0.0015	0.0			2%
N_2O - Field Burning	0.0000	0.0000	0.0000	0.0000	0.0			0%
N_2O - Crop Residues	0.0167	0.0796	0.0641	0.0887	0.2			36%
N_2O - Leaching and Runoff	0.0000	0.0000	0.0000	0.0000	0.0			0%
N_2O - Fuel	0.0003	0.0003	0.0003	0.0003	0.0			0%
Scope 1 Total	**0.0976**	**0.1604**	**0.2516**	**0.1750**	**0.6847**			

Crop	600ml rainfall Lucerne	Irrigated Crop Lucerne	Non irrigated & <600ml rainfall Lucerne		Summary of Scope 1	t CO_2e/farm	
Outputs	**t CO_2e/farm**	**t CO_2e/farm**	**t CO_2e/farm**	**total t CO_2e/farm**			**total proportion of Scope 1 emissions**
CO_2 - Fuel	0.0721	0.0721	0.0721	0.2162	CO_2	0.2162	32%
CO_2 - Lime	0.0000	0.0000	0.0000	0.0000	CH_4	0.0002	0%
CO_2 - Urea	0.0000	0.0000	0.0000	0.0000	N_2O	0.0715	0%
CH_4 - Field burning	0.0000	0.0000	0.0000	0.0000			0%
CH_4 - Fuel	0.0001	0.0001	0.0001	0.0002			0%
N_2O - Fertiliser	0.0000	0.0000	0.0000	0.0000			0%
N_2O - Atmospheric Deposition	0.0000	0.0000	0.0000	0.0000			0%
N_2O - Field Burning	0.0000	0.0000	0.0000	0.0000			0%
N_2O - Crop Residues	0.0235	0.0235	0.0235	0.0704			10%
N_2O - Leaching and Runoff	0.0000	0.0000	0.0000	0.0000			0%
N_2O - Fuel	0.0004	0.0004	0.0004	0.0011			0%
Scope 1 Total	**0.0959**	**0.0959**	**0.0959**	**0.2878**			

Appendix 3. Effectiveness of Emissions Reduction and Justification

Intervention	Effectiveness based on adoption	Justification / Research
Enhanced efficiency fertilisers	20-70% N_2O	up to 80% reduction in nitrous oxide emissions (Lam et al., 2017; Suter et al., 2016). Regional variation is important to consider, drier climates will see less reduction in emissions (GrainGrowers, 2022)
Operational efficiency	5-10% N_2O 10-20% CO_2	35-52% reduction in loss of N from delayed application – (Wallace, 2022) Up to 82% reduced ammonia volatilisation from deep placement – (Govindasamy et al., 2023; Balafoutis et al., 2017) 15-30% reduction in emissions from precision ag, or integrated strategies across the board – (Wang et al., 2025) 13-44% reduction in greenhouse gases from variable rate fertiliser application – GrainGrowers, 2022 15% reduction in fuel use from Controlled Traffic Farming – GrainGrowers, 2022 15% reduction in fuel use from improved fuel efficiency technology – GrainGrowers, 2022 19% reduction in GHGs from additional lime application to reduce N2O – GrainGrowers, 2022
Electrification	70-98% CO_2	Technology is at least a decade away – GrainGrowers, 2022

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