V.SCS.0016 Carbon accounting technical manual

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Glossary

AE	Adult equivalents (AE) is a standardised animal unit. An AE is a non-pregnant, non-lactating animal weighing 450kg LW that is maintaining condition.
Benchmarking	Comparing the performance of the enterprise against other producers and the rest of the industry.
Carbon accounting	The process used to quantify greenhouse gas (GHG) emissions from an enterprise.
Carbon footprinting	The process of quantifying GHG emissions emitted directly or indirectly by an individual, company or product.
Carbon neutrality	Net-zero carbon emissions.
Carbon sequestration	The process whereby carbon dioxide is removed from the atmosphere and stored in carbon sinks such as soils and vegetation.
Carbon sink	A reservoir that absorbs carbon dioxide from the atmosphere. Natural carbon sinks include plants, soils and the ocean.
Carbon stocks	A carbon stock refers to the quantity of carbon that has been sequestered from the atmosphere and is stored in a carbon sink.
CO_2-e	Carbon dioxide equivalents are a unit used to compare emissions from different GHGs based on their global warming potential (GWP) over a specified time period, typically 100 years (GWP_{100}).
DM	Dry matter (DM) is moisture free feed
DMI	Dry matter intake (DMI) is the amount of moisture free feed an animal consumes.
DSE	Dry sheep equivalent (DSE) is a standardised animal unit. One DSE represents the energy requirement of a 50kg dry ewe or Merino wether that is maintaining condition.
Emission intensity	Emission intensity values are based on the net emissions relative to the output (e.g. per kg beef, sheep meat or greasy wool). Emission intensity values allow for comparison and benchmarking between farms of different sizes. They are the standard unit for a product carbon footprint.
Enteric methane	Enteric methane is produced through enteric fermentation where plant material is broken down in the rumen. Enteric methane is the by-product of this process and is expelled by the animal through belching.
FullCAM	The Full Carbon Accounting Model (FullCAM) is a tool used for modelling GHG emissions from Australia's land sector.
GWP	Global warming potential (GWP) is a measure of cumulative radiative forcing, which aims to quantify the long-term contribution of a gas to global warming. Each GHG has a specific GWP value and this is relative to a specified time period (typically 100 years, but values are also available for 20-year and 50-year time horizons). For the 100-year time horizon, this is abbreviated as GWP_{100}.
GHGs	Greenhouse gases (GHGs) are gases that absorb and emit radiant energy. The main GHGs associated with agriculture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

HSCW	Hot standard carcase weight.
Livestock inventory	All information relating to livestock such as births, deaths, sales, purchases, weights and weight gain, and pregnancy status. Typically reported either at a point in time (such as June 30) or over a whole year.
LWG	The liveweight gain (LWG) of an animal. In this manual and the SB-GAF it is reported as kg/head/day.
Net emissions	Total emissions minus carbon sequestration.
NGGI	The National GHG Inventory (NGGI) accounts for and estimates Australia's GHG emissions.
Purchased inputs	Purchased products for the business such as fertilisers, herbicides, pesticides, feed, fuel, livestock and electricity.
Radiative forcing	The difference between incoming solar radiation and outgoing infrared radiation.
SOC	Soil organic carbon (SOC) is the carbon component of organic matter in the soil.
SOM	Soil organic matter (SOM) is the living and dead organic materials, other than living plant roots, found in the soil.
SB-GAF	The sheep and beef GHG accounting tool which can be used to generate a carbon account.
TGP	Total gas production.

Introduction

There is increasing concern around greenhouse gas (GHG) emissions and their contribution to global warming. Many companies, governments and industries are working to establish targets and strategies to achieve a reduction in GHG emissions.

Australia has set a target to reduce emissions to 26–28 % below 2005 levels by 2030 as part of the *Paris Agreement* (Commonwealth of Australia, 2017). Australian agricultural industries are facing increasing consumer and community pressure to reduce emissions. In response, the red meat industry has set a goal to achieve net-zero carbon emissions (carbon neutrality) by 2030 (CN30). Achieving carbon neutrality will improve future access to markets and ensure continued industry and community support.

The yearly GHG emissions generated by livestock production and other farm-related operations can be measured by conducting a 'carbon account'. A carbon account allows producers to calculate their current GHG emissions and also helps them to understand how GHGs and carbon management can impact enterprise productivity.

The information required to complete a carbon account for a beef or sheep enterprise includes:

- a livestock inventory (births, deaths, sales, purchases, weights and weight gain, pregnancy status)
- an inventory of purchased inputs
- carbon in vegetation and (potentially) soil.

A carbon account is an important tool for business planning as it allows producers to gain an understanding of their current position regarding GHG emissions and identify areas for improvement.

Reducing GHGs can yield a range of benefits, such as:

- increased productivity and long-term sustainability
- improving social licence
- improving market support for red meat
- engaging with emerging market opportunities for low carbon or carbon neutral products.

This manual

This technical manual, developed for wider industry use, is based on the outcomes and feedback received from a series of pilot carbon accounting workshops run in early 2020 across Australia. The purpose of this manual is to provide background information on carbon accounting and guidance around building a carbon account using the GHG Accounting Framework calculators developed by the University of Melbourne (greenhouse.unimelb.edu.au/Tools.htm).

This manual will be used to develop further training materials and resources to enable Australian red meat producers to build a carbon account as the industry pursues CN30.

The manual includes:

- background information on livestock-related GHG emissions
- a step-by-step guide detailing how to complete a carbon account for a beef and/or sheep enterprise using the sheep and beef GHG accounting tool (SB-GAF)
- carbon accounting example scenarios for farms
- tree and soil carbon storage on-farm
- opportunities to reduce GHG emissions
- opportunities to store carbon to offset emissions.

Carbon accounting

Understanding greenhouse gases

Major greenhouse gases

GHGs reported under the Australian government's *National GHG Inventory* (also known as the National Inventory Report or NIR (Commonwealth of Australia, 2020) include:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2)
- sulphur hexafluoride (SF_6)
- other hydrofluorocarbons and perfluorocarbons.

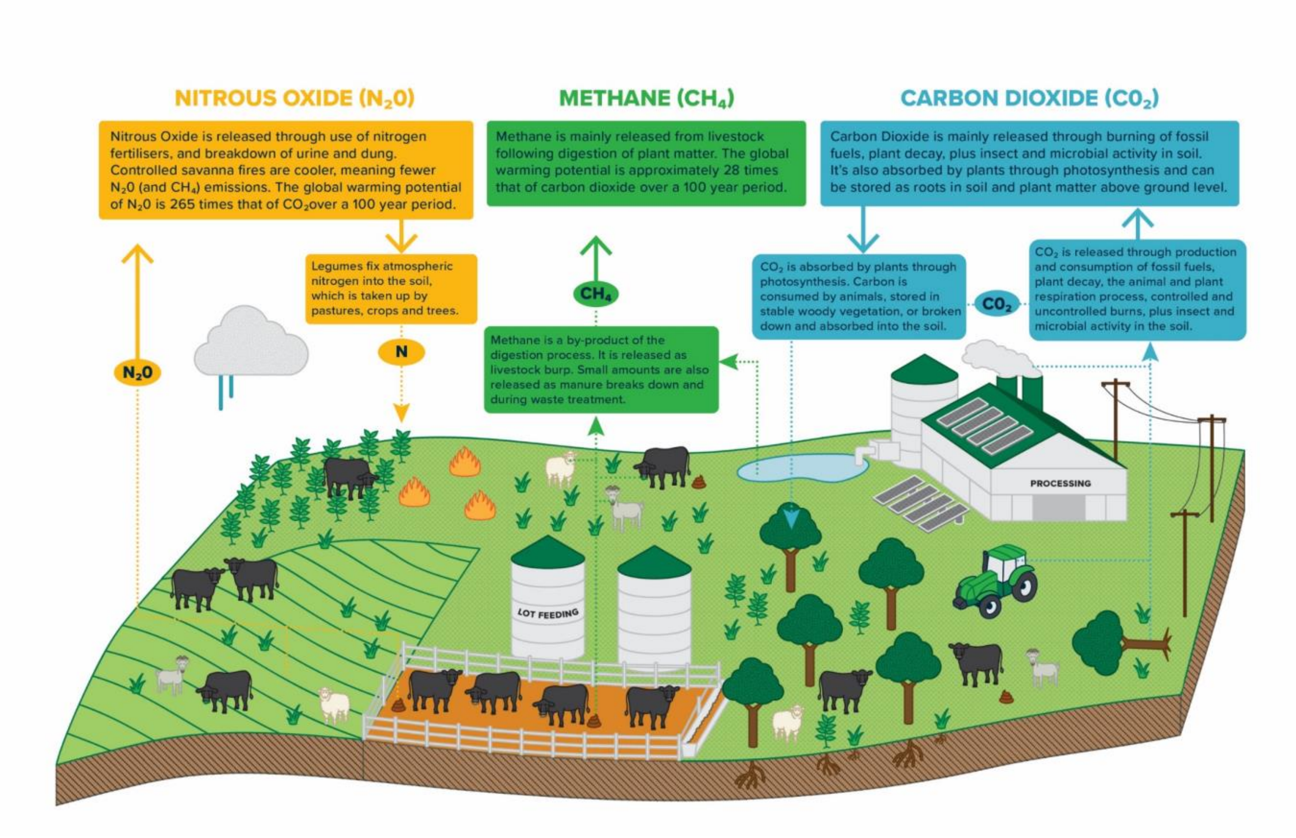
The main emissions from agricultural production are CO_2, CH_4 and N_2O (Figure 1, Figure ***2***, Figure 3). GHG emissions are measured in carbon dioxide equivalents (CO_2-e) to allow for comparison in terms of the quantity and potency of emission sources. Each gas has a different capacity to contribute to global warming. For example, methane, a potent GHG, is the largest source of livestock emissions.

Global warming potential (GWP) is a measure of cumulative radiative forcing, which aims to quantify the long-term contribution of a gas to global warming (Ranganathan et al., 2004). GWP_{100} is the global metric for assessing the average contribution to global warming over the next 100 years. Using this system, the GWP_{100} value for methane is 28 (i.e. 28 times more warming potential than carbon dioxide), and the GWP_{100} value for nitrous oxide is 265.

It is recognised by the industry that limitations may exist to the GWP_{100} method, particularly around how methane is handled. Methane breaks down in the atmosphere after about 10–14 years, and accounting for the warming effect over a much longer period (100 years) may be problematic if this breakdown factor is not accounted for.

Several other metrics have been proposed including Global Temperature Potential (GTP) (IPCC, 2014) and GWP* (Lynch et al., 2020), and these report lower impacts for methane under certain scenarios. In the future, new methods may gain more traction and become standard practice, however, for the purposes of this manual, the standard GWP_{100} values that are used by the Australian Government and internationally have been applied. We note that these GWP_{100} values are periodically updated in response to new science, and the values here align with the Australian Government guidance as of July 2020.

Figure 1: Sources of major farm greenhouse gas (GHG) emissions

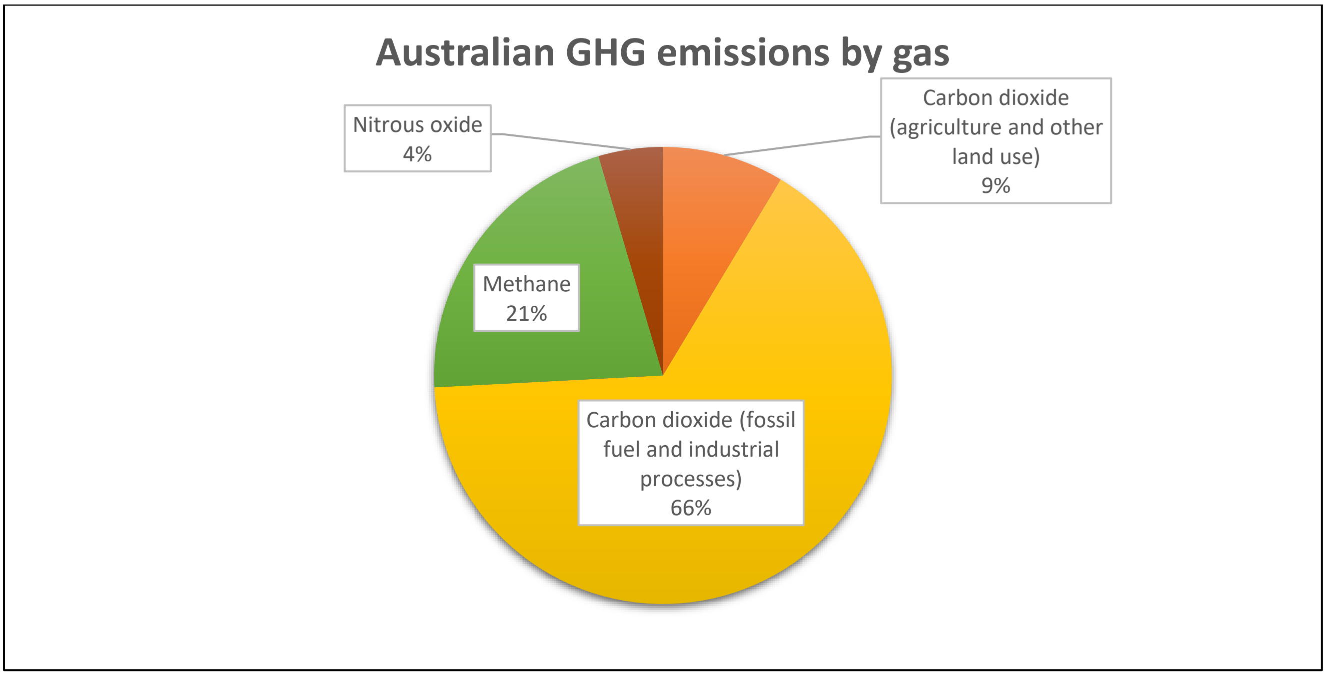


Source: CN30 Roadmap

When looking at global GHG emissions, carbon dioxide contributes the largest proportion, while methane and nitrous oxide make up a smaller part (Source: Australian Greenhouse Emissions Information System, Department of the Environment and Energy (May, 2020). These emission estimates account for multiple sectors: National GHG Inventory Total, Energy, Fuel Combustion, Transport, Fugitive Emissions from Fuels, Industrial Processes, Agriculture, Land Use, Land-Use Change and Forestry KP, Waste, Other). In contrast, methane emissions represent the majority of those generated via beef and sheep production while carbon dioxide and nitrous oxide make up a smaller proportion

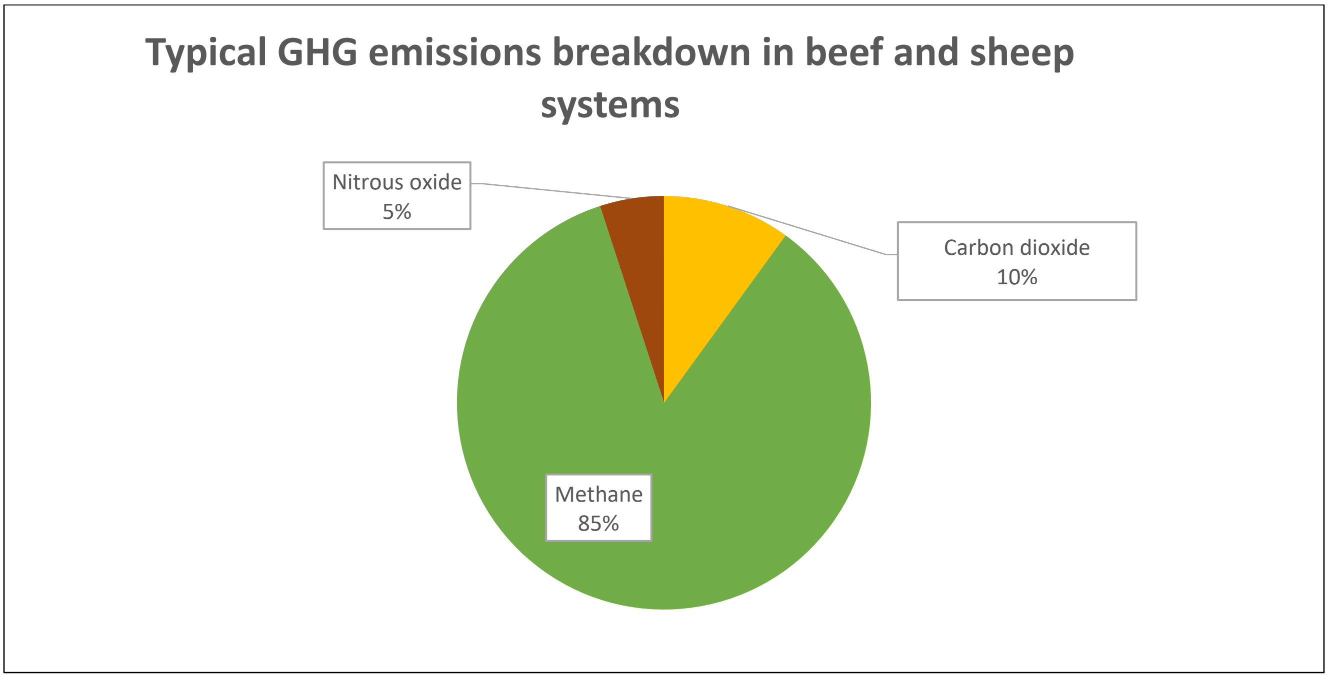
Enteric (occurring in the intestines) methane arises from ruminant digestion and manure management. Carbon dioxide emissions arise from fossil fuels used for lime and urea inputs, transport, machinery and other uses on-farm. Carbon dioxide emissions can also arise from the manufacture of purchased inputs such as fertiliser and feed. Carbon dioxide emissions or removals (storage) can also occur from changes in soil and vegetation carbon levels. Nitrous oxide emissions arise predominantly from manure excretion and fertiliser application.

Figure 2: Australian GHG emissions by gas



Source: Australian Greenhouse Emissions Information System, Department of the Environment and Energy (May, 2020). These emission estimates account for multiple sectors: National GHG Inventory Total, Energy, Fuel Combustion, Transport, Fugitive Emissions from Fuels, Industrial Processes, Agriculture, Land Use, Land-Use Change and Forestry KP, Waste, Other

Figure 3: Typical GHG emission breakdown in beef and sheep systems



Source: Wiedemann et al., 2015; Wiedemann et al., 2016. Note: the exact contributions can vary by ±10% for methane and by about ±5% for nitrous oxide and carbon dioxide

Methane from livestock

Methane is a by-product of ruminant digestion and is released into the atmosphere via belching. It represents a major energy loss for the animal, as methane has an energy content of 55.65MJ per kilogram (much the same as that of natural gas).

Methane (CH_4) is the main greenhouse gas generated in ruminant grazing systems, typically contributing between 80–90% of total farm emissions.

In grazing ruminants, energy losses from methane are in the order of 6–10% of gross energy intake. Assuming a pasture with a gross energy of 18 MJ/kg DM and metabolisable energy of 7. 3–11.7 MJ/kg DM, this loss equates to between 10–16% of metabolisable energy, depending on feed digestibility.

Reducing these emissions would substantially increase the amount of energy available for growth and reproduction. For this reason, it could be a major productivity gain if solutions or improvements were found for methane production.

Methane production per animal has a linear relationship to dry matter intake (DMI) (Charmley et al., 2016). This is true for most pasture types, but a small number of specific feed types have been shown to produce less methane per kilogram of DMI. When assessing emissions for a herd or flock, the key determinants that influence the level of these emissions are:

- livestock numbers
- livestock seasonal weights and mature weights
- growth rates and reproductive status (the factors that influence feed intake).

What is carbon accounting?

It is both difficult and expensive to measure gas emissions (and carbon dioxide uptake) on-farm. For this reason, carbon accounting is done through calculations to produce an estimate of emissions and sequestration.

Creating a carbon account allows producers to understand how GHGs interact with the productivity of the enterprise.

While it is called 'carbon accounting' for simplicity, it actually includes calculation of some nitrogen emissions (nitrous oxide) and could be better termed 'GHG accounting', but for the purpose of this manual, the two terms are considered synonymous.

Draft minimum standards for carbon accounting and carbon footprinting (Appendix 1) have been developed for the red meat industry to ensure consistency and minimise variation between different accounting methods (Wiedemann, 2019).

Standard practice is to report emissions using different classifications depending on where the emissions arise and how they relate to the business. These are termed emission 'scopes' according to the GHG Protocol (ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf) (Ranganathan et al., 2004). Standards developed by the GHG Protocol govern the reporting and accounting of these GHG emissions.

According to the GHG Protocol Ranganathan et al. (2004),chapter four, page 25, emissions are defined into three scopes:

- **Scope one:** emissions are direct GHG emissions from sources that are owned or controlled by the company.
- **Scope two:** emissions account for GHG emissions from the generation of purchased electricity consumed by the company.
- **Scope three:** emissions are a consequence of the activities of the company but occur from sources not owned or controlled by the company.

Some examples of scope three activities are those arising from the extraction and production of purchased materials, the transportation of purchased fuels, and those from the use of sold products and services.

These can be further broken down into two sources on-farm:

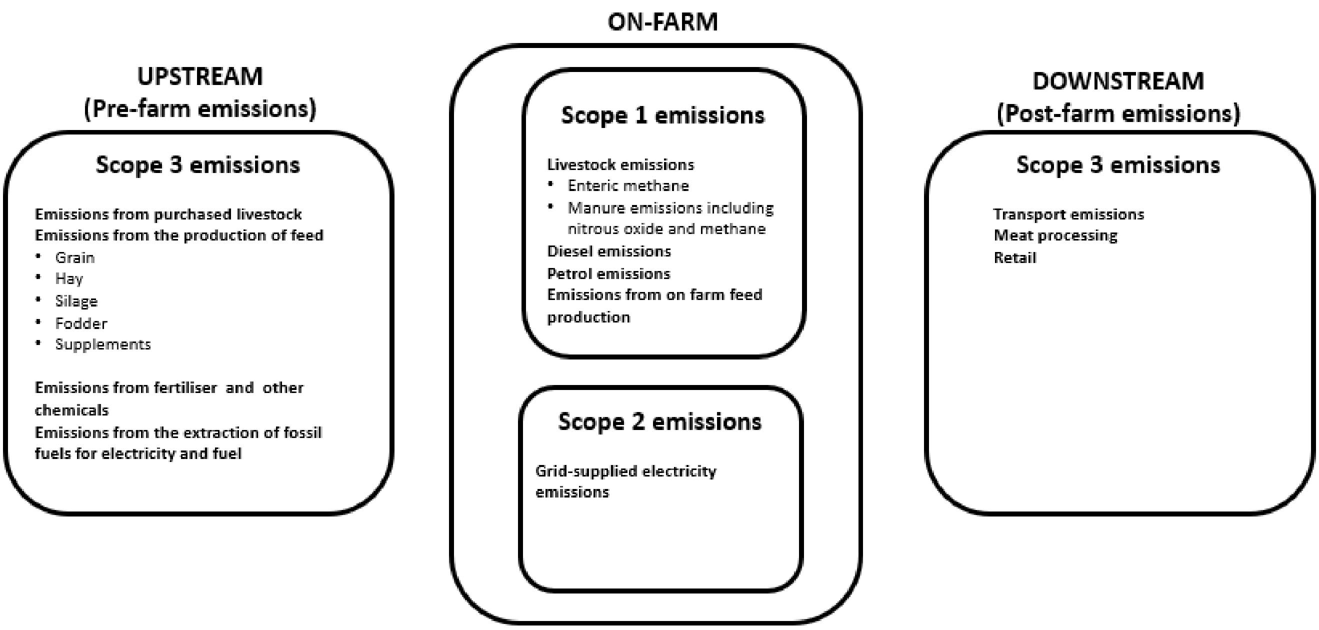
- **Upstream scope three:** emissions from pre-farm sources, such as the production of purchased supplementary feed, fertilisers and purchased livestock.
- **Downstream scope three:** emissions from post-farm sources, such as meat processing.

Emissions can also be described with the terms direct and indirect emissions:

- **Direct emissions** are emissions from sources that are owned or controlled by the company.
- **Indirect emissions** are a consequence of the activities of the company but occur at sources owned or controlled by another company (Ranganathan et al., 2004) .

Sources of emissions, by scope, for a grazing enterprise are outlined in Figure 4.

Figure 4: Examples of scope one, two and three emission sources for a grazing system



Many businesses are primarily interested in scope one and two emissions, because these are the emissions generated directly by the business. These can also be termed 'on-farm emissions'. In Australia, under the National Greenhouse and Energy Reporting (NGER) system, businesses are required to report scope one and two emissions if they exceed certain thresholds.

However, it is important to note that there are no requirements to report livestock-related emissions under NGER and most agricultural businesses are well below the emission thresholds. In business accounting, scope three emission reporting is generally optional (Ranganathan et al., 2004).

If you only focus on scope one and two emissions in a livestock enterprise it is difficult or impossible to compare (benchmark) companies accurately, because each may operate in a different part of the supply chain (breeding, growing, finishing etc.). For the same reason, it is problematic and not advised to determine an emission intensity value based only on scope one and two emissions for benchmarking purposes.

A carbon footprint requires scope one, two and three emissions to be included. This is required for carbon neutral certification under systems such as the Federal Government *Climate Active* program (climateactive.org.au/).

Carbon accounting is the process by which producers can determine their net GHG emissions on an annual timeframe. A carbon account includes two key elements:

1. GHG emissions from:
    - enteric methane from ruminant production
    - carbon dioxide from fossil fuels required for energy use, transport and purchased inputs such as fertiliser and supplementary feed
    - direct and indirect emissions of nitrous oxide from fertiliser application and excreta
    - methane from manure.
2. Carbon related to vegetation and soils on-farm:
    - Carbon that has been removed from the atmosphere through sequestration in vegetation and soils, or emitted to the atmosphere through, for example, vegetation clearing or soil disturbance/degradation.

Greenhouse Accounting Framework (GAF) tool

Producers can create a carbon account for their farm by downloading the appropriate GAF tool from: piccc.org.au/Tools. These tools have been created by the University of Melbourne and in the case of the sheep and beef calculator, by Integrity Ag & Environment and the University of Melbourne in partnership with MLA. The tools are free to access. They estimate the total GHGs emitted from a farm and identify the sources of these emissions using the most up to date Australian National GHG Inventory (NGGI) methods.

Sheep and beef GHG accounting (SB-GAF) tool

This manual focuses on the SB-GAF tool, which was developed for beef and sheep farms in 2020. The SB-GAF tool focuses on emissions produced by livestock and major purchased inputs, and contains one module for estimating sequestration from tree planting. Currently, it does not include an estimation tool for measuring changes in soil carbon (positive or negative), nor does it include a tool for estimating vegetation carbon loss (e.g. from tree clearing). This may be developed in future versions of the tool.

Full Carbon Accounting Model (FullCAM)

Presently, tree and soil carbon can be estimated using FullCAM. FullCAM incorporates biological and management processes that impact on carbon stocks and the flow of carbon in agricultural systems. FullCAM predicts biomass, litter and soil carbon pools, and accounts for human-induced land-use change practices and changes in major GHG emissions.

FullCAM is currently used to generate Australia's national GHG emissions account for the land sector (Commonwealth of Australia, 2020).To download FullCAM (free download) go to: industry.gov.au/data-and-publications/full-carbon-accounting-model-fullcam.

FullCAM has recently been updated and the current version of SB-GAF needs to be updated to match the tree-sequestration data in the new release of FullCAM. This will be conducted as part of ongoing MLA CN30 activities.

Carbon accounting for beef cattle and sheep systems

Accessing the sheep and beef GHG accounting tool (SB-GAF)

To download the SB-GAF, go to: piccc.org.au/Tools and then click on the SB-GAF link. The file should automatically download and, once downloaded, it can be accessed from the downloads folder on your computer.

Open the file, rename it (perhaps include the year the carbon account is for) and save it. Once downloaded, renamed and saved, the tool can be used offline.

What you will need

The information required to utilise the carbon accounting tool should be available from your farm taxation records, management records, or your memory. This includes:

- **Livestock inventory:** births, deaths, purchases, sales, weights and liveweight gain (LWG), weaning rates and reproductive status of animals. This contains the main information used to predict livestock-related emissions, such as enteric methane emissions. This information could exist in livestock reconciliation records for taxation or records in a livestock management program.
- **Records of farm inputs:** fertilisers, bought animal feed, fuel, electricity and purchases. This information is needed to estimate GHG emissions resulting from goods that you purchase from other companies. This information should be available in your tax records.
- **Tree planting** including area (ha), species and planting date (if available).
- **General farm information** (usually you can do this from memory).

Inputs to other enterprises (e.g. cash cropping) operating on the same farm need to be separated as this tool currently only accounts for livestock activities.

While the tool can be run for any year, we suggest selecting a ‘representative’ year that wasn't strongly influenced by good or bad seasons, and preferably when the flock/herd was reasonably stable. This will give the most indicative starting point. Seeing there is often not a ‘representative’ year to pick from because change is always occurring, it can be useful to average results from two to three years to get a baseline.

Using data from an unusual year (drought or elevated rainfall) may give inaccurate results, particularly for calculating emission intensity (emissions divided by LW or wool outputs). Calculating emissions intensity requires that the outputs are from a stable herd or flock. In a year where sales were artificially elevated to reduce livestock numbers (for example, going into drought) it is inaccurate to divide emissions by livestock sales and the model is not sophisticated enough to remove the effect of this.

This is similar for financial records, where returns may remain high going into a drought because of elevated sales, but this may not be a true reflection of business performance (unless sales are high by using gross profit as sales less purchases plus inventory change). On the other hand, if you have a year where you are trying to build your herd or flock, and therefore have minimal sales, the simple calculation of emission intensity (emissions divided by sales) will be over-estimated as a result of reduced output relative to livestock numbers (just like your financial records may indicate less money coming in). The tool is not sophisticated enough at this stage to correct for these high or low sale events, so users need to compensate for this aspect to gain realistic results.

How to use the livestock emissions calculator

The ‘data input – beef’ and ‘data input – sheep’ tabs are the only tabs that require data to be input into them. Step-by-step instructions are provided below.

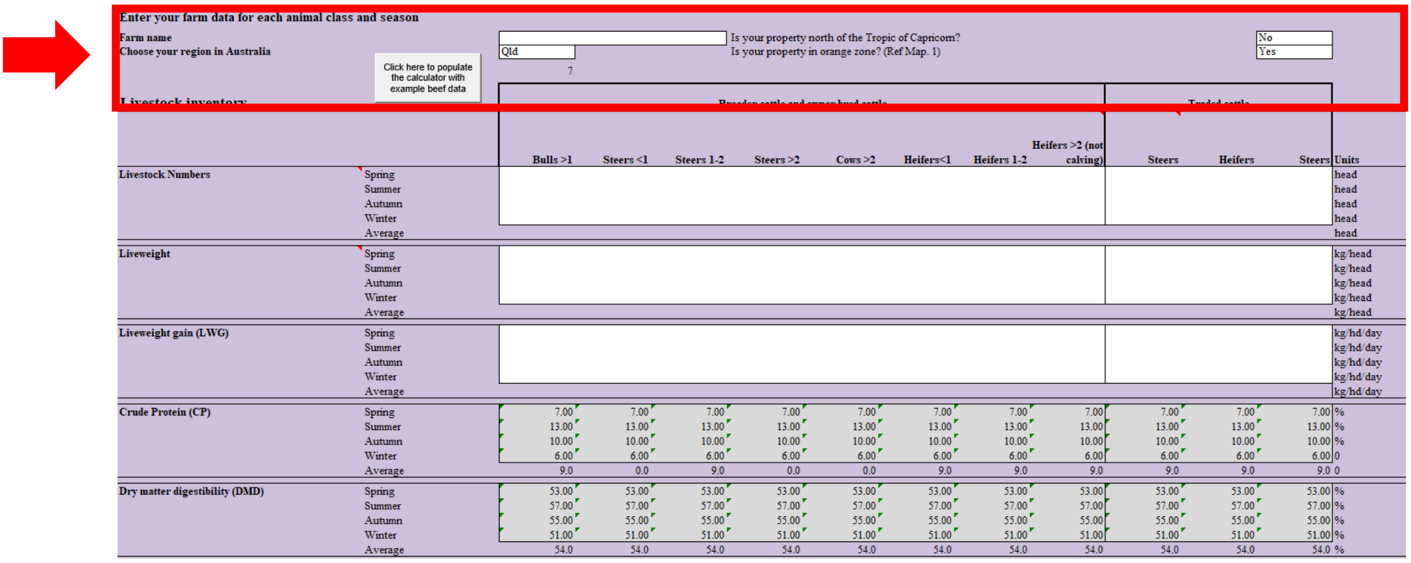
There is also a six-minute video available online to help explain how to input beef cattle data into SB-GAF, (integrityag.net.au/beefcarboninformationrequest). This video can also be used as a guide for inputting sheep data as the data input pages for beef and sheep are relatively similar.

Step one: Farm details

Start at the top of the data input sheet and provide some basic information about your farm (Figure 5):

a. Input your **'farm name'**
b. Input your farm location details by selecting from the dropdown menu in each of these three questions:
   i. **choose your region in Australia**
   ii. **is your property north of the Tropic of Capricorn?**
   iii. **is your property in the orange zone? (Ref Map. 1 in SB-GAF)**

Figure 5: Farm details section on the data input page



Step two: Livestock inventory

To complete the livestock inventory section of the spreadsheet, ensure you have access to accurate and up-to-date livestock records, including livestock numbers, liveweights (LWs) and LWG.

If you would like an example of the data that goes in these cells, press the grey button located below the farm detail sections, **'Click here to populate the calculator with example beef data.'** Note that once you press the grey button, you will not be able to undo it and will need to replace the example data with your own.

For beef cattle, the livestock inventory is separated between breeder owner, bred cattle and traded cattle. For sheep, it is separated between breeding flock and trade sheep.

a. **Livestock numbers**: Input livestock numbers for each livestock category as an average for each season throughout the year. This should take into account stock losses, sales and purchases. Traded cattle should be placed in the separate category labelled 'traded cattle'.
b. **Liveweight (LW)**: Input the average LW (kg/head) of each livestock category in each season. This should be an average weight for the season. If you do not know LW, it can be calculated from the LWG (if known). To calculate LW from LWG, see Figure 6.

For example, as seen in Figure 6, to calculate the LW of '**steers < 1'** in summer, the LW from the previous season is added on to the average LWG of that season and the previous season, and multiplied by the number of days in a season (91.25). If cattle are born in winter, the LW for spring would follow on from the winter LW.

When entering the LW of calves and lambs do not enter the birthweight. Instead, an average of LW across the season is required. In the instance of calves born in the middle of spring, in both the '**steers < 1'** and '**heifers <1'** columns the average weight for the season would be calculated by adding the birthweight to the growth rate and multiplying it by half the days in the season.

For example, assuming a 35kg birth weight and growth rate of 1kg/head/day for calves for the first season, the average weight for spring would be 81kg (Figure 7).

c. **Liveweight gain (LWG)**: Input the estimated average daily LWG (kg/head/day). This should match the LW entered in the section above. If the LW across two seasons is known, then the LWG can be calculated from this. Figure 8 shows the calculation of LWG from LW. Find the difference in weight between the two seasons (amount of growth) and divide this by the number of days in the season to give you the growth per day.

Figure 6: LWG calculation (these functions can be found by clicking on the grey box in the spreadsheet to show example data)

		Bulls >1	Steers <1	Steers 1-2	Steers >2	Cows >2
Livestock Numbers	Spring	8	82	0	0	211
	Summer	8	82	0	0	209
	Autumn	8	82	0	0	208
	Winter	8	0	0	0	207
	Average	8	62	0	0	209
Liveweight	Spring	800	81	0	0	475
	Summer	800	=E27+AVERAGE(E33,E34)*91.25			489
	Autumn	800	245	0	0	513
	Winter	800		0	0	529
	Average	800	166	0	0	501
Liveweight gain (LWG)	Spring	0.00	1.00	0.00	0.00	0.00
	Summer	0.20	1.00	0.00	0.00	0.30
	Autumn	0.00	0.60	0.00	0.00	0.24
	Winter	-0.20		0.00	0.00	0.10
	Average	0.00	0.8666667	0.00	0.00	0.16

Figure 7: Calculating the LW for the birth season for calves and lambs based on the LWG

		Bulls >1	Steers <1	Steers 1-2	Steers >2
Livestock Numbers	Spring	8	82	0	0
	Summer	8	82	0	0
	Autumn	8	82	0	0
	Winter	8	0	0	0
	Average	8	62	0	0
Liveweight	Spring	800	=35+(45.6*E33)		0
	Summer	800	172	0	0
	Autumn	800	245	0	0
	Winter	800		0	0
	Average	800	166	0	0
Liveweight gain (LWG)	Spring	0.00	1.00	0.00	0.00
	Summer	0.20	1.00	0.00	0.00
	Autumn	0.00	0.60	0.00	0.00
	Winter	-0.20		0.00	0.00
	Average	0.00	0.8666667	0.00	0.00

Figure 8: Calculating LWG from LW

Livestock inventory		Breeder cattle an			
		Bulls >1	Steers <1	Steers 1-2	Steers
Livestock Numbers	Spring	40	475	575	
	Summer	35	490	470	
	Autumn	30	485	235	
	Winter	30	505	45	
	Average	34	489	331	#DIV/(
Liveweight	Spring	700	90	310	
	Summer	718	108	380	
	Autumn	655	149	416	
	Winter	646	218	485	
	Average	680	141	398	#DIV/(
Liveweight gain (LWG)	Spring	0.70	=(E28-E27)/91.25		
	Summer	0.20	0.46	-0.30	
	Autumn	-0.70	0.75	0.40	
	Winter	-0.10	1.00	0.75	
	Average	0.03	0.60	0.36	#DIV/(

Step three: Purchase inventory

a. In **'no. head purchased'** enter the total number of livestock purchased for each livestock category over the year.
b. In **'purchase weight (LW/hd)'** enter the average LW (kg/head) when purchased.
c. On the beef data input page, select **'region where most cattle purchased'** for the breeding herd and trade cattle from the dropdown list and enter **'% of cattle purchased from this location.'** Check that these

numbers add up to 100%. On the sheep data input page, enter the **'% of sheep purchased'** as either Merino or cross-bred.

Step four: Sale inventory

a. In **'no. head sold'** enter the total number of livestock sold in each category over the year.
b. In **'sale weight (LW/h)'** enter the average LW (kg/head) when sold.

Step five: LWG (traded cattle)/LWG (traded sheep)

This section automatically populates when you enter information into the purchase inventory and sale inventory. No action is required.

Step six: Wool (only relevant on sheep input page; Figure 9)

a. Enter the total **'number shorn'** for each category.
b. Enter the **'wool shorn kg/hd'** for each category**.** This is intended to reflect wool shorn from wool produced on the farm over the past 12 months (i.e. gross wool production). If sheep are purchased with substantial amounts of wool this wool should be removed. If sheep are sold with substantial wool this should be added.
c. **'Greasy wool production (kg/yr)'** will automatically populate based on the data entered in the cells above.
d. Enter **'clean wool yield'** as a %.

Figure 9: Wool section on data input – sheep

50	Number shorn		26		314	1309		340	655				
51	Wool shorn kg/head		5.5		2.5	3.5		2	2				
52	Greasy wool production (kg/yr)		143	0	785	4581.5	0	680	1310	0	0	0	7499.5
54	Clean wool yield		65		65	65		70	70				%
55													
56	Clean Wool (t/year)		0.09	0.00	0.51	2.98	0.00	0.48	0.92	0.00	0.00	0.00	5.0
57													
58	Carbon content of Wool	45.2											%

Step seven: Percentage of cows calving/ewes lambing

Enter the calving rate/lambing rate. This should be calculated by dividing the number of calves/lambs born by the number of cows or ewes joined. If calving/lambing occurs over more than one season, ensure the total value matches the annual calving or lambing rate. This should be a percentage.

Step eight: Purchased inputs

For mixed sheep/beef enterprises be sure to split the purchased inputs between sheep and beef to avoid doubling up.

Fertiliser

a. Enter **'urea fertiliser'** used in tonnes of urea used for pasture or crops used for grazing livestock only.
b. Enter **'other N fertiliser'** as tonnes of N. This requires that you calculate the amount of N based on the tonnage and the percentage of N in the fertiliser.
c. Enter **'single super phosphate'** in tonnes.
d. Enter **'limestone applied to soils'** in tonnes.
e. Enter **'fraction'** of limestone (relates to the fractional purity of limestone. One is set as a default value in the tool).

Energy and fuel

a. Select the **'electricity source'** for the farm from the drop-down menu.
b. Enter **'annual diesel consumption'** for the livestock enterprise only in litres/year. This should include on-road fuel use related to the business.
c. Enter **'annual petrol consumption'** for the livestock enterprise only in litres/year. This should include on-road fuel use related to the business.
d. Enter **'annual electricity use'** relevant for livestock enterprise only. If the whole farm is used for livestock, this might include workshops, offices and shearing sheds, and pumps.
e. Enter **'grain purchase'** If purchased for both cattle and sheep ensure you split this value into the proportion used for each.
f. Enter **'cottonseed purchase.'** If purchased for both cattle and sheep ensure you split this value into the proportion used for each.
g. Enter **'hay purchase.'** If purchased for both cattle and sheep, ensure you split this value into the proportions used for each. If hay is produced on-farm, the emissions generated by this activity should be accounted for in the inputs section (e.g. diesel use for tractors, fertiliser, etc.), and therefore, it would not be added into this section. If a contractor is used to cut and bale the hay, you could estimate the amount of diesel they used and enter it into the diesel consumption to account for this.

Step nine: Savannah burning (only on 'data input – beef')

Savannah burning is only applicable to properties in northern Australia. If not applicable, leave this section blank.

a. Select appropriate options from drop-down boxes for:
    - rainfall
    - vegetation class
    - patchiness
    - fuel class size
    - fire season.
b. Enter **'years since fire'.**
c. Enter **'fire scar area (ha)'.**

A description of these classes can be found under section 5.7 in volume 1 of the *National Inventory Report 2013.*

Step10: Vegetation

Note: When filling in this section **start from the top and work your way down**. Dropdown box options change as you go, because they are dependent on the option selected above.

a. Select appropriate options from drop-down boxes for:
    - state
    - region
    - species of tree
    - soil type.
b. Enter the **'area of trees (h)'.**
c. Enter the **'age of trees (year)'.**

Many tree species aren't represented in this simple calculator created from multiple runs of the Full Carbon Accounting Model (FullCAM). Estimated sequestration is indicative only and a more definitive result can be obtained by running FullCAM.

It is only an indicative estimate, and more detail can be gained from specialist modelling. For indicative purposes, if the species on your farm aren't included, you can choose a species that will most closely resemble your species or used the mixed environmental plantings.

Data summary

To view a breakdown of your farm's emissions go to the **'data summary'** tab (Figure 10). The main values to focus on are:

1. **'Net farm emissions'** are the total emissions produced by the farm minus carbon sequestration from trees. This value will largely reflect the size of the enterprise. Net emissions are given as a total across the whole farm (labelled 1 in Figure 10) and then separated between beef and sheep (cells C37 &D37). Emissions are also reported for each 'scope' of gas. Scope 1 emissions (blue section in Figure 10) will usually be the largest source by a large margin. If there are large numbers of purchased livestock, the emissions from these will appear in the 'scope 3' section (red section in Figure 10), and these can also be substantial. Emissions from electricity are shown as 'scope 2' (green section in Figure 10). The breakdown of the totals is given in the cells above the total.
2. **'Emission intensity'** values (labelled 2 in Figure 10) allow comparison and benchmarking between farms of different sizes. The expected range of emission intensity values can be seen in Table 2. These values will vary depending on enterprise type, region and management practices. Note that an emission intensity value is often reported as a carbon footprint. The values here are **not a complete carbon footprint**. However, if the numbers are entered correctly, and the full beef or sheep system is accounted for (breeding, growing, finishing) the results may be around 90–95% of the emissions of a beef or sheep carbon footprint to the farm gate[1]. Accuracy in determining a carbon footprint is mainly related to ensuring the balance of livestock products (liveweight and wool) and the total livestock numbers are accurate and reflect a stable flock or herd, and purchased livestock are accounted for. Establishing this livestock balance is critical to the outcome. Other aspects that need to be considered on a case-by-case basis include the use of other inputs such as manure or use of other fertilisers or feed types not included in the calculator. Carbon footprints are also required to include carbon losses from vegetation clearing or soil carbon loss, and carbon storage in growing vegetation or as a result of improved soil management.
3. **'Summary t CO_2-efarm'** (labelled 3 in Figure 10) shows a breakdown of the different scope 1 gases produced. These are the emissions released directly from the farm. As a general guide, CH_4 (methane) commonly makes up between 80–90% of farm emissions, N_2O (nitrous oxide) ranges between 7–11% and CO_2 (carbon dioxide) should account for around 3–9% of emissions.

[1] Generating a full carbon footprint generally requires following guidance, such as ISO 14067 and the LEAP large ruminant and small ruminant guidelines (ISO, 2018; LEAP, 2015b, 2015a). For a carbon neutral registration, Climate Active also have guidelines that need to be followed (https://www.climateactive.org.au/sites/default/files/2019-11/Climate%20Active%20Guide.pdf)

Figure 10: SB-GAF data summary page

Beef & Sheep Greenhouse Accounting Tool

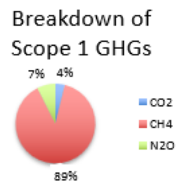
Outputs	beef t CO_2e/farm	heep t CO2e/farm	total t CO2e/farm
Scope 1 Emissions			
CO_2 - Fuel	13.59	8.57	22.17
CO_2 - Lime	0.00	0.00	0.00
CO_2 - Urea	0.00	0.00	0.00
CH_4 - Fuel	0.03	0.01	0.04
CH_4 - Enteric	611.91	507.44	1,119.35
CH_4 - Manure Management	0.19	0.13	0.32
CH_4 - Savannah Burning	0.00		0.00
N_2O - Fertiliser	0.00	1.00	1.00
N_2O - Urine and Dung	22.64	26.14	48.79
N_2O - Atmospheric Deposition	2.26	2.71	4.98
N_2O - Leaching and Runoff	12.74	10.84	23.58
N_2O - Savannah Burning	0.00		0.00
N_2O - Fuel	0.06	0.04	0.10
Scope 1 Total	**663**	**557**	**1,220**
Scope 2 Emissions			
Electricity	1.62	6.73	8
Scope 2 Total	**2**	**7**	**8**
Scope 3 Emissions			
Fertiliser	0.00	0.00	0.00
Purchased feed	32.98	9.93	42.91
Herbicides/pesticides	0.00	0.00	0.00
Electricity	0.24	0.66	0.90
Fuel	0.71	0.45	1.16
Lime	0.00	0.00	0.00
Purchased livestock	171.74	0.00	171.74
Livestock on agistment			
Scope 3 Total	**206**	**11**	**217**
Carbon Sequestration			
Carbon sequestration in trees	-17.25	0.00	-17.25
Net Farm Emissions	**853**	**575**	**2,874**

1

Emissions intensity		
Sheep meat (breeding herd) excl. sequestration	**6.7**	kg CO2-e / kg LW
Sheep meat (breeding herd) inc. sequestration	**6.7**	kg CO2-e / kg LW
Wool excl. sequestration	**24.8**	kg CO2-e / kg greasy
Wool inc. sequestration	**24.8**	kg CO2-e / kg greasy
Beef excl. sequestration	**14.6**	kg CO2-e / kg LW
Beef inc. sequestration	**14.3**	kg CO2-e / kg LW

2

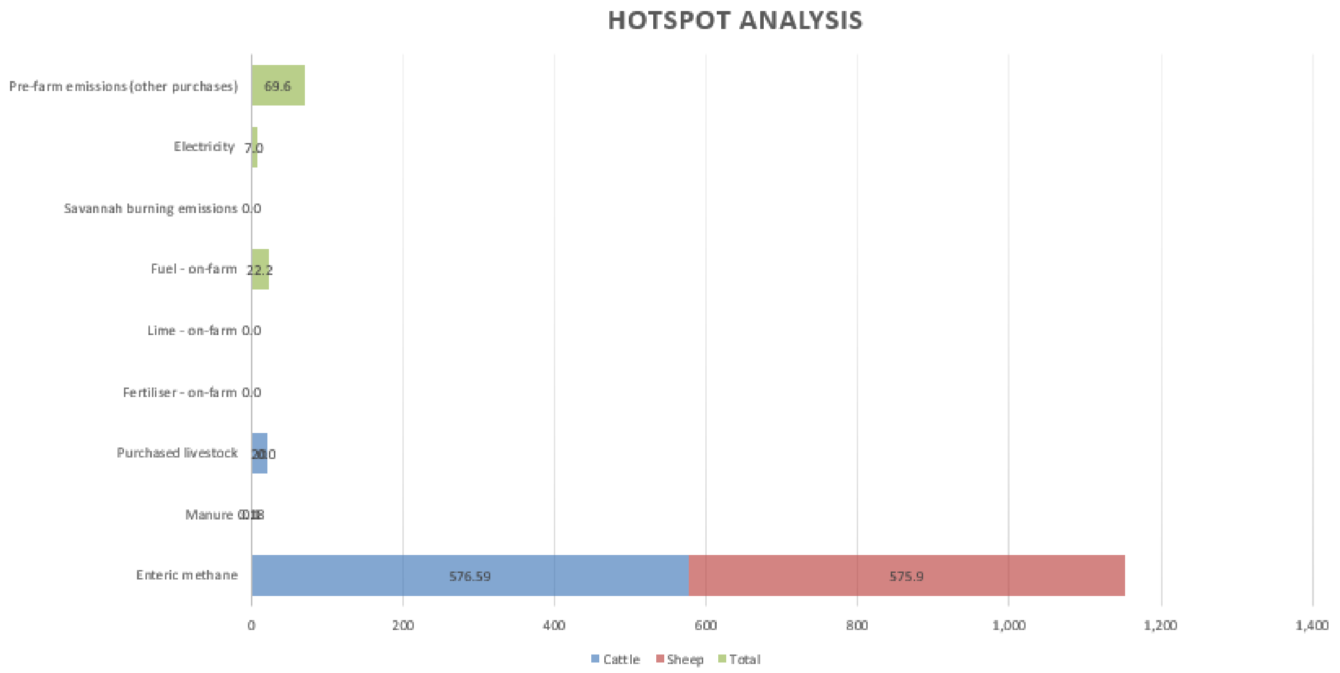
Summary t CO2e/farm	
CO_2	48
CH_4	1,121
N_2O	94



3

A visual breakdown (hotspot analysis) of major emission sources (excluding sequestration) is displayed on the **'data summary page**' (Figure 11). In the example provided, this graph highlights the large contribution of enteric methane from livestock in comparison to other farm inputs.

Figure 11: Hotspot analysis



Livestock emission benchmarks

Table 1 shows indicative tonnes of CO_2-e for different livestock stocking units. Dry sheep equivalents (DSE) and adult equivalents (AE) are standardised animal units used in southern and northern Australia, respectively.

One DSE represents the energy requirement of a 50kg dry ewe or Merino wether that is maintaining condition. A general rule is that one DSE will consume 1kg of dry matter (DM) per head per day (MLA, 2019).

A yearling steer may be equivalent to eight DSE, and a lactating cow (and calf) may be equivalent to 15–20 DSE depending on body weight, stage of lactation. An AE is a non-pregnant, non-lactating animal weighing 450kg LW (Department of Primary Industries, 2007).

Expected values for emissions intensity from various livestock products (excluding sequestration) are provided in Table 2).

Table 1: Approximate benchmark emission rates from livestock per stocking rate unit

Livestock class	Total GHG (t CO_2-e)[2]
1 AE (450kg non-lactating cow)	1.75
1 DSE (50kg dry ewe or Merino wether)	0.23–0.25

[2] These values are indicative only and should not be used to substitute for a properly calculated carbon account. Estimate includes enteric methane, manure emissions and emissions from purchased inputs. Variation exists between regions and states, which influences manure related emissions, and between different production systems that use more or less inputs.

Table 2: Expected values for emission intensity excluding sequestration (Wiedemann et al., 2015; Wiedemann, Yan, Henry, et al., 2016a)

Emission source	Emissions intensity expected range [3]	Unit
Sheep meat – breeding, growing, finishing	6–10	kg CO_2-e /kg LW
Wool	20–35	kg CO_2-e /kg greasy wool
Sheep meat (trade sheep) excluding scope 3 livestock emissions	2.5–4	kg CO_2-e /kg LWG
Beef – breeding, growing, finishing	9–18	kg CO_2-e /kg LW
Beef traded cattle excluding scope 3 livestock emissions	5–9	kg CO_2-e /kg LWG

Emissions from common inputs

Emissions from common farm inputs are provided in kg CO_2-e per unit in Table 3.

Table 3: Scope three emissions from common farm inputs

Inputs		
Feed		
Cotton seed	kg CO_2-e/kg	0.2
Cereal grain (wheat, barley, sorghum)	kg CO_2-e/kg	0.2
Cereal hay, dryland	kg CO_2-e/kg	0.2
Urea		
Fertilisers		
Urea	kg CO_2-e/kg	1.5
DAP	kg CO_2-e/kg	1.4
Single super	kg CO_2-e/kg	0.9
Lime application		
Transportation		
B-double 38T load	Per tonne-kilometre (tkm)	0.00007
Semi-trailer 25T load	tkm	0.00011

*Values derived from AustLCI or from the authors own life cycle inventory (LCI) calculations.

[3] Expected emission intensity values are based on results from studies conducted by Wiedemann et al. (2015) and Wiedemann et al. (2016a)

Livestock carbon accounting scenarios

Beef

This section details different scenarios relating to herd efficiency. It demonstrates the impact that herd parameters have on emission intensity and net farm emissions.

Three beef cattle scenarios were included:

1. a weaner scenario
2. a feedlot entry steer scenario
3. a grass-finished scenario.

For each scenario, there is an average production example, maximum production example and a low GHG example. The farm selected was in southern Queensland, and sold cattle as weaners, feeder steers and grass-fed bullocks at different times, depending on feed availability and by utilising other blocks of land. We have used these different finishing scenarios to show the range in emissions from different herd structures and market specifications.

Scenario one: Weaner production.

For key herd parameters for this scenario see Table 4. In the average production example, there were 212 breeders joined, and the enterprise had weaning rate of 78%. Steers were sold at nine months of age at an average sale weight of 272kg with an average growth rate of 0.72kg/head/day. The herd was self-replacing, and the farm was a relatively low input farm (no fertiliser and a small quantity of feed purchased). The farm was producing 50,279kg of beef. Using these numbers, the farm emissions were found to be 650 tonnes CO_2-e and the emission intensity was 12.9kg CO_2-e/kg LW.

For the maximum production scenario, the weaning rate was increased to 90%, and the growth rate of steers was increased to 1kg/head/day up until sale (Table 4). This increased beef turn-off to 62,025kg.

Farm emissions increased to 691t CO_2-e due to the higher number of calves and lactating cows and therefore increased methane and manure emissions. However, the emission intensity decreased to 11.1kg CO_2-e/kg LW because the additional beef turn-off compensated for the slight increase in emissions.

To maintain higher growth rates for steers, grazing cattle on improved pasture or crops could be an option. This would require inputs such as diesel and fertiliser. The addition of 2t of urea and 1000L of diesel for the establishment of a forage crop did not change emission intensity significantly and resulted in a 1% increase in farm emissions.

For the low GHG example, the same herd performance was assumed from the maximum production scenario. The herd size was reduced (reduced breeder numbers to 177 head) but total beef production was maintained at the same level as the average production scenario (Table 4). This achieved a reduction in farm emissions and emission intensity compared to the average scenario.

Table 4: Herd parameters – beef scenario one

	Herd parameters					Farm emissions	Emission Intensity
	Weaning (%)	Turn-off age steers (mths)	Steer turnoff weight (kg)	Steer ADG (kg/hd/day)	Beef turnoff (kg LW)	Tonnes CO_2-e	Kg CO_2-e/kg LW
Average	78	9	272	0.72	50,279	650	12.9
Max. prod.	90	9	309	1.0	62,025	691	11.1
Low GHG	90	9	309	1.0	50,461	560	11.1

Scenario two: Feeder steers

For this scenario, the herd on the same farm was restructured to allow steers to be grown out to feedlot entry weight with the same stocking rate. Key herd characteristics for the feeder steer scenario can be seen in Table 5.

In the average production example, there were 164 breeders joined and the enterprise had a weaning rate of 78%. Steers were sold at 18 months of age at an average sale weight of 400kg, growing at an average of 0.65kg/head/day. The farm emissions were found to be 614 t CO_2-e and the emission intensity was 12.1kg CO_2-e/kg LW. Total beef production reflected steer sales and sales of surplus heifers and cull cows.

Table 5: Herd parameters – beef scenario two

	Herd parameters					Farm emissions	Emission Intensity
	Weaning (%)	Turn-off age steers (mths)	Steer turnoff weight (kg)	Steer ADG (kg/hd/day)	Beef turnoff (kg LW)	Tonnes CO_2-e	Kg CO_2-e/kg LW
Average	78	18	400	0.65	50,931	614	12.1
Max. prod.	90	12	400	1	58,439	632	10.8
Low GHG	90	12	400	1	50,293	545	10.8

To achieve maximum production the weaning rate was increased to 90% and steer growth rate was increased to 1kg/day, reaching the sale weight of 400kg at 12 months rather than 18 months. This improvement in herd efficiency resulted in a decrease in emission intensity. To reduce farm emissions (low GHG example in Table 5:), breeder numbers were reduced to 141 head, while still maintaining the 90% weaning rate and approximately the same beef production as the average scenario.

As explained in scenario one, additional inputs such as diesel and fertiliser for fodder cropping or pasture management may be required to achieve higher growth rates, and these were included by increasing diesel and fertiliser to reflect some additional forage cropping. These have a relatively very low impact on emissions and emission intensity.

These simple scenarios demonstrate the concepts, but specific assessments are required to find the best balance of feed quality, feed availability and herd feed requirements from region to region, along with the economics of making these changes to production.

Changing herd productivity and herd structure can improve GHG efficiency (emission intensity) and can reduce total emissions without reducing beef production. Examples provided here show reductions of around 10 – 15 % in total emissions using this strategy.

Scenario three: Grass finished bullocks

In this scenario, the herd was restructured to produce grassfed bullocks. For key herd parameters for this scenario see Table 6.

In the average production example, 129 breeders were joined, and the enterprise had a weaning rate of 78%. Steers were sold at 36 months of age at an average sale weight of 583kg, growing at an average growth rate of 0.5kg/head/day. These herd parameters produced farm emissions of 625 t CO_2-e and the emission intensity was 12.5kg CO_2-e/kg LW.

In the maximum production example, increasing the weaning rate to 90% and the growth rate to 0.7kg/head/day allowed heavy steers to be turned-off earlier (at 32 months) at heavier weights. As seen in Table 6, this improved herd efficiency and resulted in a reduced emission intensity (10.9kg CO_2-e/kg LW) but also led to increased farm emissions because there were more young cattle in the system.

To achieve a reduction in farm emissions (low GHG example in Table 6), breeder numbers were reduced to 101 which resulted in a farm emission of 555T CO_2-e and emission intensity remaining the same at 10.9kg CO_2-e /kg LW.

To increase steer growth rate to an average of 0.7kg/head/day, 5t of urea and 1500L of diesel were added to account for forage cropping to facilitate this increased growth rate. This resulted in a slight addition to farm emissions and emissions intensity. As noted with the feeder steer scenario, a specific assessment is required to find the best balance of feed quality, feed availability and herd feed requirements from region to region, along with the economics of making these changes to production.

Table 6: Herd parameters – beef scenario three

	Herd parameters					Farm emissions	Emission Intensity
	Weaning (%)	Turn-off age steers (mths)	Steer turnoff weight (kg)	Steer ADG (kg/hd/day)	Beef turnoff (kg LW)	Tonnes CO_2-e	Kg CO_2-e/kg LW
Average	78	36	583	0.5	50,083	625	12.5
Max. prod.	90	32	674	0.7	62,746	687	10.9
Low GHG	90	32	674	0.7	50,765	555	10.9

Key points

These scenarios show that changing herd productivity and herd structure can improve GHG efficiency (emission intensity) and can reduce total emissions without reducing beef production.

The main factors a producer can influence are weaning rates and growth rates in young cattle, but others such as calving at two years compared to three years and reducing mortalities can also help reduce emission intensity.

To reduce total emissions, it's necessary to reduce herd numbers. Fewer animals in the system mean less methane production and nitrous oxide from urine and dung and therefore lower total emissions.

If weaning rates and growth rates are increased, productivity can be maintained or increased, resulting in a win-win for both productivity and emissions. Cullen et al. (2016) reported a 22–28% reduction in emissions intensities on western Queensland cattle properties, which was achieved primarily through increased weaning. However, this type of change will require more inputs, which may increase cost-of-production if the beef output isn't increased.

Sheep

Scenario one: Sheep

This sheep example demonstrates how changes in flock parameters can result in improved flock efficiency, which can lower farm emissions and emission intensity. This example is based on a moderately productive lamb breeding operation.

Key flock parameters:

- 70kg LW ewes, 1309 ewes joined.
- Self-replacing flock, with a lambing rate of 100 %.
- Lambs sold at nine months of age at 45kg.

Using the flock parameters above, the system produced 666 t CO_2-e per year and had an emission intensity of 7.3kg CO_2-e/kg LW (Table 7).

A low GHG scenario was run with an extreme change in flock characteristics to demonstrate the maximum changes that could be achieved (see Table 7). In this example, the marking rate was increased to 150 %, ewe numbers were reduced, mortality was reduced, lamb ADG was increased, and lamb sale weight increased, and kg of turnoff increased. This resulted in a reduction in farm emissions to 585 t CO_2-e and an emission intensity of 5.7kg CO_2-e. A reduction in ewe numbers reduced farm emissions and by maintaining the increased marking rate, output can also be maintained or increased. An increase in lamb sale weight to 50kg and a 2 % reduction in mortalities further decreased emission intensity. Similarly to the beef examples, this simple scenario demonstrates the concept, but specific assessments are required to find the best balance of feed quality, feed availability and feed requirements from region to region, along with the economics of making these changes to production.

Table 7: Flock parameters – sheep scenario one

	Flock parameters							Farm emissions	Emission Intensity	
	Marking (%)	Ewe no.	Mortality (%)	Turnoff age lambs (mths)	Lamb turnoff weight (kg)	Lamb ADG	Kg turnoff (LW)	Tonnes CO_2-e	Kg CO_2-e/kg LW	Kg CO_2-e/kg greasy
Average	100	1,309	4	9	45	0.14	63,115	666	7.3	27.1
High prod, Low GHG	150	1,000	2	9	50	0.16	78,000	585	5.7	21.1

While this was an extreme scenario, it showed that production could increase (in this case by 19 %) while farm emissions decreased by 10 %.

Next steps: Opportunities and benefits from reducing emissions or storing carbon

Net GHG emissions can be reduced through carbon sequestration in trees and soils, through the implementation of management practices that generate fewer emissions, and through methane mitigation technologies. Some of these strategies can be implemented immediately. In contrast, others require further research before they are available for use in beef and sheep farms across Australia.

Emissions reduction via livestock productivity

As demonstrated in the example livestock carbon accounting scenarios above, improvements in herd productivity can lower both net GHG emissions and emission intensity. These improvements include:

- **Increased weaning/marking rate:** Although this will increase net farm emissions as there are more animals in the systems producing enteric methane, a reduction in emission intensity will occur as efficiency has increased.
- **Reduction in numbers while maintaining output**: If increased weaning/marking rates are combined with reduced breeder numbers, the output can be maintained, and both net emissions and emission intensity can be reduced. Culling unproductive animals will reduce methane emissions. Animals that take longer to reach market weight produce more methane as they remain on-farm for longer periods and are producing little output in return.
- **Increased growth rate from weaning to slaughter:** Earlier finishing means slaughter weights are reached at a younger age, and lifetime methane emissions are reduced. To achieve this, additional inputs such as diesel and fertiliser for improved pastures/fodder crops or purchased feed will generally be required. The reduction in emissions caused by the increased productivity significantly outweighs the emissions generated from the use of these additional inputs.
- **Breeding for improved feed conversion efficiency:** There is a relationship between net feed efficiency and methane (Alford et al. 2006). Selecting animals based on their feed conversion efficiency is likely to reduce methane emissions and lower emission intensity. Modelling by Alford et al. (2006) found that after 25 years of using bulls identified as being more feed efficient, annual methane emissions for a herd were 15.9% lower.
- **Joining heifers/ewes at an earlier age:** This reduces the number of animals in the herd relative to calves or lambs born.

Emission reduction via enteric methane mitigation technologies

There are a range of methane mitigation technologies, but many of these are undergoing research and development and are not yet available in Australia. Some of these technologies offer improved animal productivity in addition to reductions in methane production.

Feed additives

Feed additives can reduce enteric methane production by targeting the pathway of methanogenesis.

Asparagopsis

Asparagopsis is a genus of red marine macroalgae which is rich and diverse in lipid and tannin content (Kinley et al., 2016). Previous work has evaluated the effects of 20 tropical macroalgae species in in vitro fermentation parameters (total gas production (TGP) and methane production) under incubated rumen fluid fed low-quality roughage diet (Machado et al., 2014).

The results from Machado et al. (2014) showed that *Asparagopsis* was the most effective species in reducing total gas and methane production whilst having the least negative effect on fermentation. Furthermore, *Asparagopsis* is shown to have high concentrations of calcium, sodium, magnesium, iron and manganese compared to a basic ration (Roque et al., 2019) providing the additional benefit of potentially needing less mineral supplementation in other forms. However, this would only be relevant at relatively high feeding rates. Although not currently commercially available in Australia, this emission reduction technology is expected to be available in the next 2–3 years (Department of Environment and Energy, 2019).

Machado et al. (2016) identified the natural products responsible for antimethanogenic activity in *Asparagopsis*. Bromoform and brominated halomethane are the most abundant compounds which inhibit the production of methane. The mode of action is through enzymatic inhibition by a reaction which reduces vitamin B_{12}. This results in reduced efficiency of the cobamide-dependent methyltransferase step, which is required for methanogenesis (Kinley et al., 2016).

Previous work has demonstrated the anti-methanogenic effects in vitro. Kinley et al., (2016) investigated the anti-methanogenic potency at low inclusion rates over 72 hours using Rhodes grass as a feed substance. At a 1% (OM basis) inclusion rate, there was a significant reduction in methane production. At inclusion rates greater than 2% there was no detectable methane production over the 72 hours of the experiment, implying from this experiment that a 2% inclusion rate is necessary for constant reductions when compared to Rhodes grass. Overall, abatement of > 85% was observed compared to the control.

Similar results were also observed in in vitro work where the 2% inclusion rate in a Rhodes grass diet resulted in TGP reductions of 61.8% and methane reduction of 98.9% after 72 hours, compared with the control. However, at an inclusion rate greater than 2%, volatile fatty acid (which is the product absorbed by the host ruminant) production decreased, (Machado et al., 2016) and this could have a negative production effect on cattle. Similar results were observed by Roque et al. (2019) who demonstrated that at an inclusion rate of 5% OM, TGP decreased by ~ 50% and methane production by ~ 95% compared to a basic ration.

Recently, the Kinley et al. (2020) in vitro study explored the use of *Asparagopsis* in beef cattle fed a high grain diet total mixed ration(TMR) over 90 days. The results from the experiment showed that a lower inclusion rate of 0.2% OM of *Asparagopsis* could decrease methane emissions by 98% compared to the baseline. At mid (0.05% OM) and high (0.2% OM) inclusion rates, significant LW increases were observed compared to the control.

For example, liveweight gain was of 137kg and 130kg, respectively compared to the 113kg for control steers at the end of the 90-day treatment period. This translated to an increased average daily weight gain of 51% and 42% for the mid and high inclusion levels compared to the control steers during the concluding 60 days of the experimental treatment, though it is noted that growth rates, which varied between 1.52kg/d and 1.26kg/d, were below the level expected in commercial feedlots for all treatments.

Regarding feed intake, dry matter intake (kg/d) was only marginally higher (7.5%) in the mid inclusion level compared to the control. These results support the theory that additional energy was derived from the feed rather than being lost as methane. This study illustrates the production co-benefits *Asparagopsis* could provide, if the results are supported by further feeding trial research. *Asparagopsis* research is continuing and commercial companies are currently focusing on scale up to supply *Asparagopsis* in Australia.

3-nitrooxypropanol (3-NOP) synthetic product

3-NOP is a synthetic product that can be added as a feed supplement (Vyas et al., 2018). Previous work has shown promising results, making it a potential methane mitigation option in beef cattle. It has a similar mode of action to bromochloromethane without the potentially harmful and toxic effects on the environment (Romero-Perez et al., 2014). 3-NOP is thought to inhibit the enzyme methyl-coenzyme M reductase (MCR), which is required in the last step of methanogenesis by rumen archaea (Dijkstra et al., 2018; Vyas et al., 2018).

Romero-Perez et al. (2014) evaluated the potential of 3-NOP inclusion in Angus cattle fed high forage diets (backgrounding diets) with different inclusion rates over a 28-day experimental period. At the highest inclusion level (4.5mg NOP/kg body weight), methane production decreased by 33%. 3-NOP was most effective in reducing methane production during the first two hours after feeding. Post two hours, a negative transitory effect on methane production was seen (methane production increased) and 3-NOP is absorbed, metabolised and/or washed out from the rumen.

At the two lower inclusions rates, methane production was similar to the control at 13 hours after feeding, implying that its efficacy for the given inclusion rates decreases over time. However, this was not the case for the highest inclusion level, which consistently remained lower than the control treatment throughout the experimental period. This suggests that regular supplementation would be more effective than a single dose at lower inclusion rates to extend the benefits of 3-NOP.

Vyas et al. (2018) examined the dose-response of 3-NOP on methane production and the dry matter intake (DM) I for high-forage and high-grain diets in Canadian beef cattle. The results from the study showed that under the high-forage diets the total CH_4 emissions decreased significantly (23%) at 200 mg/kg DM 3-NOP, with a positive correlation seen for the 100 and 150 mg/kg DM 3-NOP treatments. High-grain diets also saw a decrease in CH_4 emissions with increasing 3-NOP supplementation, with a 45% emission reduction under 200 mg/kg DM 3-NOP compared with baseline.

MLA are currently commissioning research into 3-NOP in the Australian feedlot sector. Once approval of the use of 3-NOP is granted by the Australian Pesticides and Veterinary Medicines Authority (APVMA) and further dose-response and efficacy trials have been conducted in Australian systems, it is intended that 3-NOP will become commercially available for Australian producers.

Other feed additives

Currently, *Asparagopsis* (Machado et al. 2014; Li et al. 2018; Roque et al. 2019) and 3-NOP (Duval and Kindermann 2012; Hristov *et al*. 2015) are relevant mostly for intensive cattle systems and the federal government has flagged these technologies as high priorities in their emissions reduction activities. These technologies may become applicable to extensive systems as research into their alternative delivery mechanisms progresses.

There are other additives, forages and supplements that are used in both southern and northern systems that have antimethanogenic potential. These include oils (Beauchemin *et al.* 2008; Moate *et al*. 2011, 2014; 2016; Veneman *et al*. 2015; Eckard et al. 2010; Eckard & Clark 2019) and tannins (Grainger *et al*. 2009; Beauchemin *et al.* 2008; Woodward *et al.* 2004; Carulla *et al.* 2005; Eckard et al. 2010; Eckard & Clark 2019) found in plants (e.g. legumes) and by products of agricultural processing (e.g. grape marc, whole cotton seed, cold pressed canola meal).

Anti-methanogenic pastures

A range of pastures have anti-methanogenic properties, including Birdsfoot trefoil, Biserulla, Eramophela, Leucaena and Desmanthus. These species contain tannins that inhibit the formation of methane in the rumen of livestock.

Of these, the species that have received most attention are those suited to sub-tropical climates such as Desmanthus and Leucaena. There are temperate legumes that also contain tannins, however most of the commonly used pasture legumes (such as Lucerne and white and red clover) don't have enough tannin in leaf material to have an effect on enteric methane.

The temperate legumes that have been shown to effect methane through leaf tannin content include Lotus, Biserulla, Crownvetch, sainfoin (*Onobrychis viciifolia*), and Sulla (*Hedysarum coronarium*). Note that tannin content alone may be a general, rather than a reliable, predictor of anti-methanogenic potential of pastures.

Desmanthus

Desmanthus is a legume that has a mitigation effect resulting from the high amount of tannins (Vandermeulen et al., 2018), which are known to inhibit the activity of protozoa, fibre degraders and methanogenic archaea which leads to a reduction in hydrogen available for methane (CH_4) production (Kumar et al., 2014).

Trials have shown that steers grazing on Desmanthus-Buffel grass for 90 days in winter achieved a 40kg greater weight gain than steers just on Buffel grass alone, exemplifying the potential Desmanthus has to improve average daily gain (ADG) and thus reduce methane emissions indirectly through a higher turnover of cattle in the herd (Gardiner & Parker, 2012).

Vandermeulen et al. (2018) examined three species of Desmanthus adapted to heavy clay soils in northern Australia and determined their nutritive value and effects on in vitro fermentation in rumen fluid, compared with Rhodes grass (*Chloris gayana)* hay. Methane production measured per gram of OM (organic matter) fermented (mL/ g OM) was measured throughout the 72-hour fermentations. The chemical analysis results from the study showed that Rhodes grass had fewer total phenols than the legumes. This is negatively correlated with methane production (mL/g OM).

Additionally, hydrolysable tannins (HT) had a negative correlation with methane production per gram of OM fermented. Both *Desmanthus leptophyllus* and *D. bicornutus* had higher HT values than the reference hay and *D. virgatus,* which resulted in methane production being reduced by 36% in *D. leptophyllus* and 26% in *D. bicornutus* at 24 hours of fermentation, when compared as isolates, analogous to feeding each as 100% of intake. It is important to note that their methane mitigation potential was also influenced by season and partially through species chemical composition changes. For this study, we applied a 10% mitigation potential for cattle grazing Desmanthus, taking into account that variations in the nature of the crop and concentration of active ingredient affect this percentage (pers. coms. Ed Charmley 2020). We note that further research is underway at CSIRO (Lansdown) and these estimates should be updated when a more representative result for grazing cattle on mixed pastures is available.

Leucaena

Leucaena is another legume that can reduce GHG emissions in terms of GHG emissions per kilogram of dry matter intake (DMI) by decreasing direct enteric methanogenesis through its high amount of condensed tannins (33 to 61g/kg DM) (McSweeny & Tomkins, 2015; Suybeng et al., 2019). It follows a similar mitigation mechanism to Desmanthus.

McSweeny & Tomkins (2015) work investigated Leucaena impacts regarding GHG emissions on northern Australian beef cattle farms. Two sites in Queensland were used to conduct the experiment where rumen fluid from 20 animals in each grazing group on both sites was collected, with methane measurements occurring throughout the project period. The results from their study showed that steers grazing on Leucaena had lower daily emissions (g/head) than those grazing on grass pastures with values of 95 ± 7.9 g/head compared with 132 ± 7.1 g/head for native pasture, resulting in a maximum 28% methane abatement potential.

McSweeny & Tomkins (2015) observed similar results, namely improved production outcomes for steers grazed on Leucaena versus Rhodes grass pastures, where the mean daily gains over a total of 192 days were 0.58 and 0.28kg/d for steers grazing on Leucaena or grass pasture, respectively. Data was then extrapolated to an intensity basis using mean carcase weight, which resulted in Leucaena finished steers to be estimated at 335g CH_4/kg HSCW hot standard carcase weight) compared with 596g CH_4/kg HSCW for grass pastures. The increased animal growth is likely due to the increased digestibility of Leucaena as well as increased energy utilisation (Piñeiro-Vázquez et al., 2017).

It has been observed that the intake of Leucaena slows when cattle are continuously grazed over long periods. Harrison et al. (2015) reported that Leucaena ingestion decreased from 0.95kg/head/day in the first 100 days to 0.59kg/head/day over 500 days. Whether reductions occur because the quality decreases with the age of Leucaena or from some other factor is unclear. However, it is important to take the potential for reduced intake levels into account when using this as a mitigation strategy.

MLA continue to invest in Leucaena research and have recently released a sterile variety that was developed at the Redlands Research Facility in Queensland. Further information can be found here.

Offsetting emissions: Tree carbon

Trees can sequester large amounts of carbon that can be used to offset GHG from livestock and farm operations. Planting trees to offset emissions does not necessarily have to result in reduced productivity. Planting trees on small areas of marginal land, areas that are not easily accessible or in laneways should not adversely impact on productivity and can sequester significant amounts of carbon on some farms (Doran-Browne et al. 2016).

Planting trees to offset emissions is a long-term solution as it takes several years to establish trees and receive the benefits. Trees offer other benefits such as:

- increased biodiversity
- erosion and salinity control
- provision of shelter for livestock (Doran-Browne et al., 2016; George et al., 2012).

However, trade-offs associated with tree plantings on agricultural land can include:

- the reduction in the land available for agricultural production
- water security concerns because of reduced runoff (Polglase et al., 2011)
- increased competition with pastures for water and light (Doran-Browne et al., 2016)

MLA continues to invest in research understand how to optimally position and grow trees to ensure that carbon storage can be balanced with productivity co-benefits.

Types of on-farm tree plantations include:

- environmental plantings (a mixture of local native species)
- agroforestry (farm forestry planting)
- commercial plantations.

Common types of environmental plantings and agroforestry in Australia are alley farming, windbreaks/ shelterbelts and riparian buffers. Alley farming consists of rows of trees planted where grazing or cropping occurs in between the trees. Alley farming also addresses dryland salinity issues.

Windbreaks/shelterbelts involve planting trees so that they can be used as:

- barriers to reduce the impact of wind
- conserve soil moisture
- reduce wind erosion
- provide shelter/protection for pasture and livestock.

Riparian buffers involve planting trees and other vegetation along waterways (George et al., 2012).

The potential suitability of planting trees for carbon sequestration to offset emissions is largely dependent on factors such as the availability of land, rainfall and the impact that tree planting will have on agricultural land (Doran-Browne et al. 2018). The rate of carbon sequestration is determined by the age of the tree, species, environmental conditions (soil type, rainfall) and management (Unwin and Kriedemann 2000; Doran-Browne et al. 2018). Although higher rates of carbon sequestration occur in new plantations, mature plantations will slowly continue to sequester carbon until they reach maturity (Unwin & Kriedemann, 2000).

In a study conducted by Doran-Browne et al. (2016), a wool-growing property in southern NSW, which had 39% of the farm covered in native tree species, sequestered an average of 4T CO_2-e/ha per year in trees and 25T 5CO_2-e/ha per year in soil over 32 years.

These sequestration rates were enough to offset livestock emissions after four years, making the property carbon neutral as more carbon was sequestered in trees and soil than what was emitted from livestock.

Doran-Browne et al*.* (2018) showed three properties with vegetation cover of 20% and stocking rates of up to 22 DSE/ha that were carbon positive for more than 25 years after trees were planted.

A study by Doran-Browne et al. (2018) found that vegetation cover of 20% or more of total property area was enough to offset all livestock emissions on beef and sheep properties in south-eastern Australia.

Henry et al. (2015) reported carbon sequestration rates in trees per year for 100 years for three major Australian wool production regions. In the northern tablelands of NSW, sequestration rates were estimated to be 3T CO_2 per ha per year for mixed native species and 5T CO_2 per ha per year for exotic pines.

Carbon sequestration rates were estimated to be 1.4T CO_2 per ha per year for mixed native species in the 'sheep-wheat' zone of WA, and 7T CO_2 per ha per year for the chenopod shrublands of the 'pastoral zone' of SA.

On these farms, vegetation was integrated into the farming system, and none of the farms were carbon neutral. The largest reductions approached 19% of livestock emissions over a 100-year period (Wiedemann, Yan, Henry, et al., 2016b) which corresponds to about 50% over a 40-year period.

Examples of successful tree plantings are provided in Figure 12, Figure **13**, and Figure ***15***.

Figure 12: Example of fenced remnant vegetation on a property in NSW

Image: Jenny O'Sullivan

Figure 13: Example of shelterbelts on a sheep property

Image: Jenny O'Sullivan

Figure 14: Cows sheltering next to riparian fencing

Image: Jenny O'Sullivan

Offsetting emissions: Soil carbon

An increased concentration of carbon in soils leads to:

- increased water holding capacity
- increased soil fertility
- increased soil aggregation
- increased cation exchange capacity
- reduced susceptibility to erosion.

Implementation of management options that lead to increased soil organic carbon levels also contribute to improved productivity, profitability and sustainability (Sanderman et al., 2010). The ability of soils to sequester CO_2 from the atmosphere and store it in the soil carbon pool offers potential GHG emission mitigation.

There is great potential for carbon sequestration in soils as they hold the largest terrestrial store of organic carbon (Luo et al., 2010; Viscarra Rossel et al., 2014). Soils store 2–4 times the amount of carbon stored in the atmosphere, and four times the amount of carbon stored in plants (Bell & Lawrence, 2009). Small variations in soil carbon can lead to large carbon sequestration potential (Luo et al., 2010). Soil organic carbon (SOC) levels in the top 30cm of soil for each state are shown in Table 8.

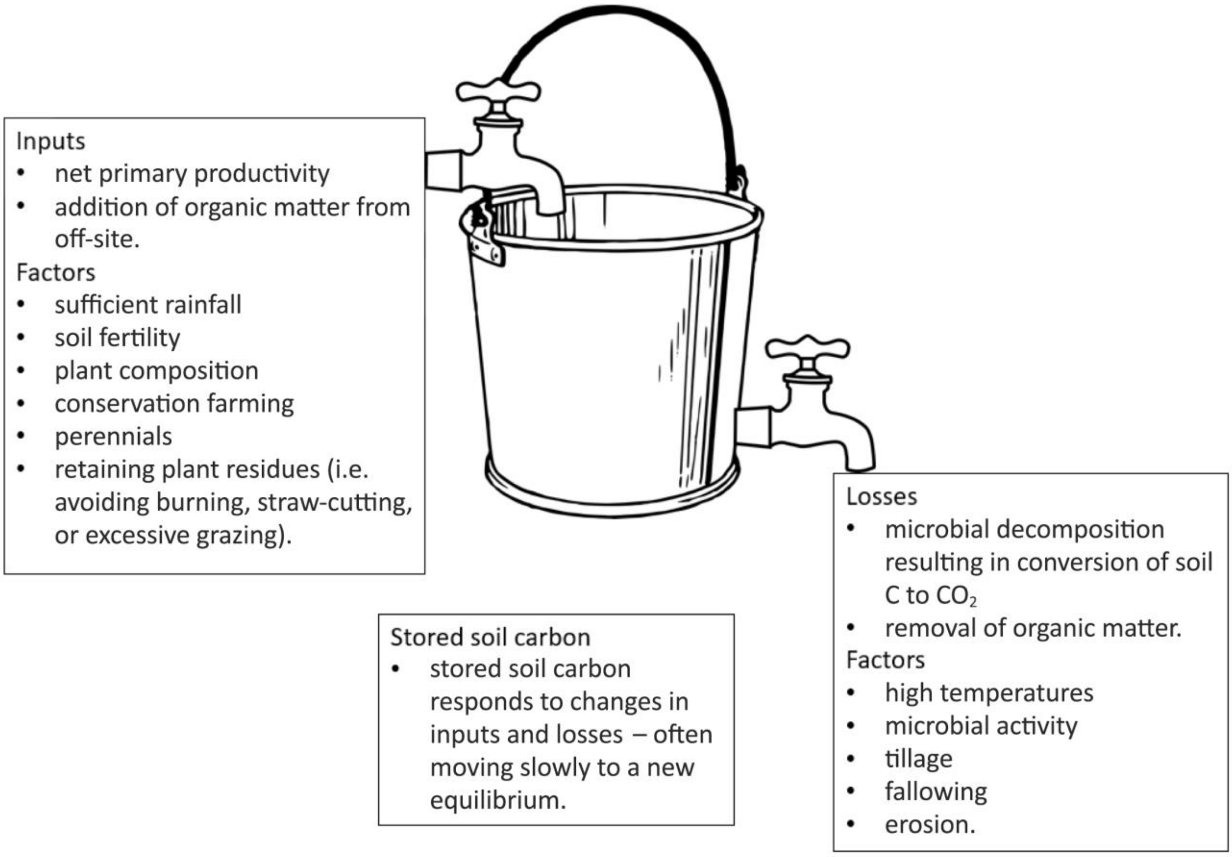
Table 8: Soil organic carbon levels 0–30cm by state (Viscarra Rossel et al., 2014)

State/ territory	Soil organic carbon 0–30cm (t/ha)
TAS	134.0
VIC	67.0
ACT	62.3
NSW	42.4
QLD	31.2
WA	25.8
NT	22.6
SA	29.7
Australia	**29.7**

Soil organic carbon (SOC) levels are constantly in a state of flux as they respond to environmental and management changes. Soil carbon increase is a function of the quantity of carbon added to the soil and how much is retained.

Carbon generally will reach an equilibrium over time meaning sequestration rates will slow or stop at some point after management changes are initiated, though sequestration can continue over many years. The cycling and storage of soil carbon can be thought of as a bucket with two taps as shown in Figure 15. The bucket represents the potential quantity of SOC that can be stored. One tap represents inputs into the soil, which contribute to increased SOC, and the other represents SOC losses (Liddicoat et al., 2010).

Figure 15: The storage of soil carbon is determined by potential storage, inputs into and losses from the soil (reproduced from Liddicoat et al., 2010)



Soil carbon sequestration

As an example of soil carbon changes, for an Australian soil with a bulk density of 1.3 g/cm^3, to achieve a one percent increase in soil organic carbon (SOC) over 10 years in the top 30cm, approximately 15–30 tonnes of organic matter would need to be added to the soil annually.

To put this into context, a two-tonne wheat crop adds approximately two tonnes of organic matter per hectare when the stubble is retained. This example highlights the fact that an increase of this size is difficult to achieve in a short period of time (Hoyle, 2013).

To put this into a pasture context, for a pasture stocked at 10 DSE/ha with 50% utilisation, approximately 4t of organic matter inputs from above ground residues are available as inputs to the soil per year.

It should be noted that it is also possible that some pasture and crop soils may lose carbon over time. Clearing land for agricultural purposes has, in most cases, resulted in a decline in soil carbon and an increase in CO_2 emissions (Robertson & Nash, 2013).

Soil carbon calculation

Total organic carbon (%) x bulk density (g/cm^3) X depth (cm).

The amount of soil carbon (t/ha) to a depth of 10cm for soil with 1.2%

Organic carbon and a bulk density of 1.3 g/cm^3 is as follows:

= 1.2 x 1.3 x 10

= 15.6 t C/ha of soil organic carbon

The loss of carbon from grasslands is determined by factors such as the occurrence, intensity and type of disturbance (Soussana et al., 2007). In some management systems continuing losses of soil carbon may contribute additional emissions from the farming system. Where soil carbon stocks are stable (either at a high stock level or low stock level) this has no impact on an annual carbon balance, though of course higher carbon stocks are beneficial for soil health and a range of other reasons.

Factors that influence soil carbon sequestration

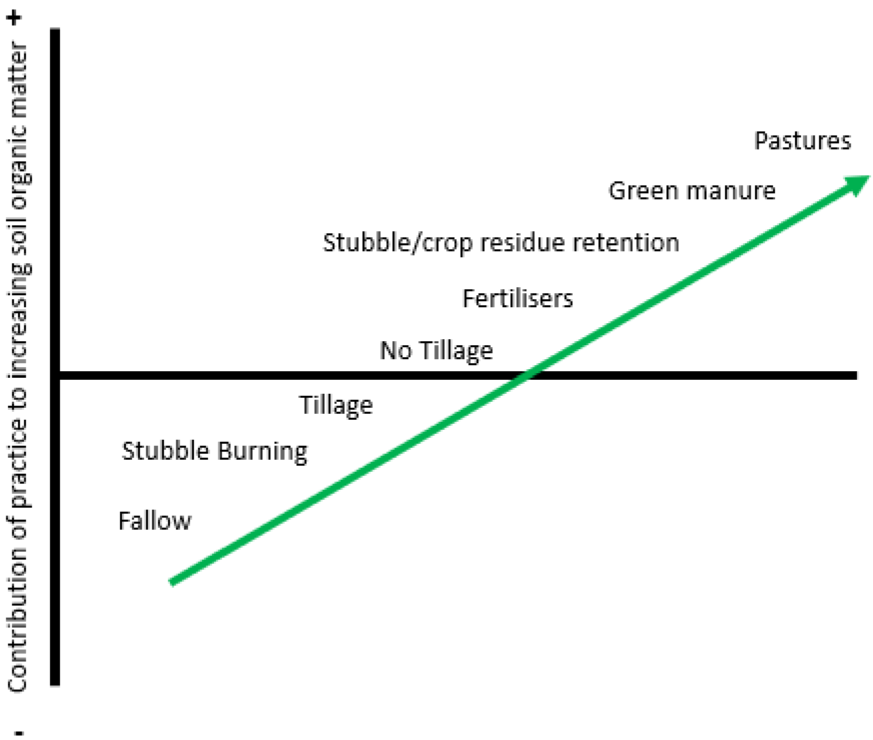
The ability to sequester soil carbon is dependent on the soil type, climate and management practices. Soil type is the primary factor determining the potential storage of soil organic carbon (SO). Clay soils typically store more SOC, and sandy soils generally store less carbon as the soil microorganisms can access the organic carbon more easily and the rate of decomposition is accelerated.

Rainfall also influences the potential SOC storage as rainfall dictates plant productivity and therefore the level of organic carbon that enters the soil. In warm climates with high rainfall, the rate of SOC decomposition is accelerated, whereas in cooler climates there is typically a greater SOC content as the rate of decomposition is reduced. As soil type and rainfall can't be influenced on a particular farm, more attention is given to management practices.

The impact of management practices on soil carbon

In general, management practices that enhance plant growth and return plant biomass into the soil will be beneficial in building soil carbon (K. Denef, C.E Stewart, J. Brenner, 2008; Lal, 2004; Sanderman et al., 2010), as will practices that reduce the loss of carbon. Figure 16 illustrates the impact different management practices have on soil carbon levels.

Figure 16: The effect of different management practices on soil carbon levels (adapted from Cotching, 2009)



Note: Pastures have the greatest potential to increase soil organic carbon (SOC) levels, particularly well-managed perennial pastures. Generally, fertilisers improve soil fertility and increase plant biomass leading to increased SOC levels.

Pastures

Shifting to perennial pastures, particularly from crop rotations, offers the greatest potential to increase soil carbon (Figure 16). In comparison to annuals, perennials have deeper and more extensive root systems. Perennial pastures have improved water utilisation to optimise the rate of potential photosynthesis. Respiratory losses of SOC may also be limited with perennial pastures due to their ability to utilise rainfall which can reduce decomposition rates via a decline in soil water content (Sanderman et al., 2010).

Doran-Browne et al. (2016) demonstrated significant increases in soil organic carbon on previously degraded soils in a South-east Australian sheep farm through perennial pastures. Over the 32 years 11,800 t CO_2-e was sequestered in the soil with sequestration rates of 2.5 t CO_2-e ha/year, which when combined with carbon sequestered in trees was enough to offset all GHG emissions produced (Doran-Browne et al., 2016).

Sanderman et al. (2013) reported significant increases in soil carbon under Kikuyu based pastures in South Australia and Western Australia; however, no significant change under Kikuyu in NSW, or under a panic-Rhodes grass pasture in Western Australia was reported. The ability of Kikuyu to sequester carbon was likely a result of the greater below-ground allocation of C and improved coverage of Kikuyu (Sanderman et al., 2013).

Chan and McCoy (2010) also noted increased soil carbon levels under perennial pastures in comparison to native pastures. In the rangelands of Southern Australia, increased soil carbon levels have been found under high coverage of perennial pastures (Waters et al., 2015). The study also noted the association between higher SOC levels and the presence of trees, with levels almost 30 % higher in areas within close proximity to trees.

Research indicates that compared with continuous cropping, crop-pasture rotations increase SOC. Badgery et al. (2013) found that in central NSW, there was a lower SOC content under land used for cropping compared with land used for pasture and pasture rotations. Similarly, a study conducted by Chan et al. (2011) in Southern NSW also highlighted the importance of the pasture phase in pasture-crop farming systems. The more pasture, the more organic matter and therefore increased SOC levels.

Fertiliser and irrigation

Although fertiliser application and irrigation may lead to increased plant growth, there is a trade-off associated with this practice. Fertilisation and irrigation of pastures will also promote microbial activity in the soil, resulting in increased decomposition rates which leads to increased CO_2 release (Gillabel et al., 2007). None the less research in Australia has shown a weak but positive association between soil P and N and SOC (Wilson & Lonergan, 2013) suggesting fertiliser and pasture improvement can increase organic matter. Trials have also revealed slightly higher SOC after long-term fertiliser applications (Schefe et al., 2015).

Grazing management

Some research suggests that there may be potential to maintain or increase soil carbon stocks over time through effective grazing management, such as grazing at an appropriate stocking rate and rotational grazing. Lower stocking rates can result in more pasture residue being returned to the soil increasing carbon inputs and the turnover of shoots and roots, leading to increased soil carbon sequestration (Conant et al., 2001; Sanderman et al., 2010). Rotational grazing is a grazing strategy where pastures are grazed for some time, and then livestock are removed from the paddock for a set time, allowing the pastures to “rest”. The length of grazing and rest periods are determined by pasture growth (Allen et al., 2013). Sanderman et al. (2015) concluded that rotational grazing does not have measurable impacts on soil organic carbon in short to medium term. Similarly, Chan et al. (2010) looked at the effect of different management practices and different pasture types on soil carbon stocks in south-eastern Australia and found no significant changes in soil organic carbon stocks as a result of management practices or pasture type. Others have suggested that this approach can increase soil carbon but evidence in the scientific literature is scarce. This emphasises the need for more long-term trials to quantify soil carbon sequestration potential.

Summary

Soil carbon sequestration rates under favourable conditions can range between 0.05 and 0.8t C/ha/year (Robertson & Nash, 2013; Sanderman et al., 2010). However, in a typical Australian grazing system, the carbon sequestration rate doesn't usually exceed 0.3t C/ha/year (Macdonald et al., 2020). Research indicates that the largest increases in soil carbon stocks are often associated with land that has formerly been degraded but has been restored, or soils that receive manure/bio-solid applications (Sanderman et al., 2010). However, it can be surprisingly difficult to achieve soil carbon increases, and even harder to measure small changes unless there is a long interval between soil sampling. None the less, considering the substantial benefits that exist from improving soil carbon levels, this represents a dual benefit to any grazing operation.

There are currently two Emissions Reduction Fund (ERF) methods available for producers to generate carbon credits through demonstrating increased soil carbon in response to changed management methods. However, due to the high costs associated with measurement of soil carbon in accordance with the methods, the value proposition for producers is difficult to demonstrate. The Federal Government's Technology Investment Roadmap includes an economic stretch target to decrease the cost of soil carbon measurement to under $3 per hectare per year, which may enable producers to be remunerated via the carbon market for activities that result in soil carbon increases.

Helpful resources:

GRDC – Managing soil organic matter

Becoming carbon neutral

Any producer can become carbon neutral by minimising emissions and offsetting any residual emissions with carbon storage in vegetation and/or soil carbon. However, to make a claim of carbon neutrality in the market place requires following the Australian Consumer Law which are governed by the Australian Competition and Consumer Commission (ACCC). One way to achieve this is to follow a third party verified system such as the *Climate Active* program which is backed by the Australian Federal Government. This requires a thorough carbon accounting and third party verification process. A carbon accounting manual for feedlots is currently being finalised. Further information on becoming carbon neutral is provided on MLAs CN30 webpage.

Frequently asked questions

Beef and sheep GHG calculator

In the SB-GAF tool, is there an allowance for emissions at the meat processing stage?

No. The calculator accounts for emissions up to the farm gate.

How are the emissions from grain and fodder purchases incorporated?

The embedded emissions associated with the production of purchased feed are reported as Scope three emissions and incorporated into the total net farm emissions and emission intensity values.

What is the difference between emission intensity for beef, sheep and wool?

The calculator will generate an emission intensity value beef, sheep meat (both reported as live weight) and greasy wool both including and excluding sequestration. Emission intensity values are based on the total emissions relative to the output (kg beef or sheep meat or greasy wool). Emission intensity values allow for comparison and benchmarking between farms of different sizes. The emission intensity for beef, sheep meat and wool differ because of fundamental differences in the system. Sheep systems are typically more efficient concerning their livestock emissions, and their emissions are also divided over two products, which generally results in lower emissions intensities than beef.

How does the calculator deal with expanding or contracting herds/flocks?

In a herd or flock that is expanding, emission intensity is likely to be higher as there will be lower sales (output) relative to total emissions and vice versa for a contracting herd or flock. The calculator is not sophisticated enough to adjust for this effect, so results will not provide an accurate benchmark. Estimated total herd or flock emissions are not affected by this.

Emissions variability

What role does cattle breed/genetics play in methane emissions? Is there a correlation between feed-efficient animals and methane emissions?

There is a relationship between net feed efficiency and methane produced (Alford et al., 2006). Selecting animals based on their feed conversion efficiency is likely to reduce methane emissions and lower emission intensity. Modelling by Alford et al. (2006) found that over 25 years of using bulls identified as being more feed efficient annual methane emissions for a beef herd were 15.9 % lower than in year one. Genetic improvement is a suitable option for extensive grazing systems where other methane mitigation options may be considered unfeasible (Vercoe, 2011). Research has indicated that there is a heritable genetic variation in methane emissions from cattle, highlighting the potential use of genetic improvement in beef and sheep herds/flocks to reduce methane emissions (Donoghue et al. 2014).

What is the relationship between DMI and methane, and how does feed quality impact this?

There is a positive, linear relationship between DMI and methane production for grazing animals on the vast majority of pastures in Australia (Charmley et al., 2016). This relationship does not hold true for animals fed a very high grain diet, where emissions are lower (Harper et al., 1999) or for animals fed on specific pastures shown to have anti-methanogenic properties (as described below).

Options for reducing net emissions

What tropical legumes have been shown to reduce methane?

Desmanthus and Leucaena are tropical legume species that have demonstrated potential methane abatement and improved animal performance. More research is currently being conducted into the potential of Desmanthus. Further information can be found here.

Are there legumes suited to a grass-based southern grazing system that have CH_4 mitigation potential?

Other legumes such as Biserrulla and Birdsfoot trefoil have the potential to reduce methane emissions by up to 20 %. Biserrulla, an annual pasture legume that is suited to regions in Southern Australia that receive an annual rainfall of between 325 – 550 mm, has demonstrated potential to reduce methane production in *in vitro* fermentation trials. Research has indicated that the methanogenic potential of Biserrulla may be influenced by the conditions the legume was grown under (Banik et al., 2013).

Birdsfoot trefoil has potential to benefit prime lamb production and wool production in the high-rainfall zones of south-eastern Australia where annual rainfall exceeds 600mm. Birdsfoot trefoil contains condensed tannins that inhibit the formation of methane in the rumen. The legume has other benefits associated with productivity, such as improved LWG, increased wool growth and potentially increased lambing rates. Persistence of birdsfoot trefoil is an issue in south-eastern Australia due to the species requiring a high photoperiod to allow for regeneration and persistence. The cost of establishment of Birdsfoot trefoil is a major adoption barrier (Doran-Browne et al. 2015).

MLA continue to conduct research into adoption and commercialisation of existing legumes that are known to have antimethanogenic properties, and also into identifying new legumes that have potential to contribute to the CN30 target as part of grazing systems.

If the focus is on maximising weaner growth rate, what long term impact will that have on overall herd emissions if mature cow weight increases?

Heavy mature cow weights will increase herd maintenance energy requirements, which will generate more emissions. However, increased growth rates will result in decreased emissions in young cattle before slaughter. It is possible for herds with heavy mature cow weights and high growth rates to have low emissions intensities, but ideally, moderate cow weight and high growth rates in young stock would be ideal.

Carbon storage

Do grasses such as Buffel grass, where the majority of plant biomass is underground, store more carbon than others?

Productive grasses that produce large quantities of biomass could improve soil carbon if it results in more biomass being trampled by livestock and returning to the soil. However, research has generally shown that soil carbon under Buffel grass is still lower than it was under native timber (Pringle et al., 2016).

Do you need to add nitrogen to the soil to store carbon?

The ability of soil to sequester carbon depends on the availability of other nutrients such as nitrogen and phosphorus, which are tied up with carbon. A 1 % increase in SOC would require between 900 – 1500kg N/ha and 70 – 120kg P/ha to produce the required organic matter to achieve this increase in SOC (Bell & Lawrence, 2009).

What are the potential soil carbon limits for various vegetation and climatic areas?

Soil type is the primary factor determining the potential storage of organic carbon. Clay soils typically store more soil organic carbon (SOC), and sandy soils generally store less carbon as the soil microorganisms can access the organic carbon more easily and the rate of *decomposition* is accelerated. Rainfall also influences the potential SOC storage as rainfall dictates plant productivity and therefore, the level of organic carbon that enters the soil. The actual level of organic carbon storage that is achieved is determined by the land management practices utilised (i.e. stocking rates – heavy grazing will result in less plant biomass entering the soil compared with low stocking rates where more plant material will enter the soil) (Carson, 2020). Average soil organic carbon levels in the top 30cm by the state are given in Table 8. These levels are only averages, so they will vary within different regions of each state and with different land use and management practices, but they are useful for indicative purposes.

How can I store more carbon, is tree planting my only option? What happens after 40 years when trees reach maturity and sequestration plateaus?

Although higher rates of carbon sequestration occur in younger trees, mature trees can continue to sequester carbon over their *lifetime*, depending on tree type (Unwin & Kriedemann, 2000). However, it is right that this rate slows and will reach equilibrium in a stable forest. There are opportunities to store carbon in soils through effective land management practices such as perennial pasture species and improved grazing management techniques. Utilising methane mitigation technologies and adopting management practices to reduce GHG emissions will reduce the amount of carbon storage required in trees and soil.

If trees are unfenced and vegetation cover is not dense, by fencing it off and allowing regeneration, we should expect an increase in carbon sequestration that can be measured?

Yes, removing stock from areas of vegetation by fencing it off will often assist in the regeneration of the vegetation, particularly if grazed with sheep or goats. This can potentially lead to increased carbon sequestration. The rate of sequestration will depend on the species of trees, environmental factors and how well the area is managed. Successful establishment of trees is often difficult, particularly in dry seasons. Mapping programs should pick up the thickening of the forest and the additional canopy cover as the trees regenerate. In addition to satellite images photos are also a good way of monitoring progress.

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Draft Final - Minimum Standards for Carbon Accounting and Carbon Footprints for Sheep and Beef Farms

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Introduction

This set of minimum standards is intended to outline the essential characteristics for assessing a carbon account and/or carbon footprint for a sheep or beef cattle farm in Australia. It does not cover items that are expected to have only a minor impact on the total carbon account or carbon footprint. The minimum standards have been developed in an iterative way through collaboration with leading researchers over two workshops held in 2019. This document is intended to be a working document and is intended to be updated and modified over time, following application in research and consulting. As a consequence, revisions and suggestions are welcomed and should be directed to the author: Stephen.wiedemann@integrityag.net.au. Periodic revisions will be issued.

Purpose

The minimum standards have been developed to provide a level of comparability regarding key aspects of carbon accounting and carbon footprinting for the red meat industry. This will enable different research groups to develop carbon accounts or carbon footprints for red meat producers with a minimum level of standardisation to avoid material differences in the results caused by different accounting methods.

To maintain brevity, the standards do not explain detailed rationale, and direct the reader to other documents to the maximum extent possible. The minimum standards do not aim to be comprehensive, and researchers or practitioners are expected to use sound scientific judgement with reference to the literature and other comprehensive standards to address issues not covered here.

It is noted that there are both similarities and differences between a carbon account and a carbon footprint. These are defined, with respect to livestock farms, as follows:

Carbon account (CA): This covers all the emissions arising within the operational and organisational boundary of the farm enterprise. It includes all scope 1 emissions and sources of sequestration. It includes scope 2 emissions from electricity. It does not include scope 3 emissions from livestock or any other source. Impacts from a CA are typically reported in tonnes of carbon dioxide (in equivalent units, CO_2-e) for the enterprise and should differentiate between scope 1 and scope 2 emissions. Exclusion of scope 3 emissions must be stated and where scope 3 livestock emissions are excluded, emissions should not be reported per kilogram of live weight or greasy wool (see carbon footprint below).

Operation and Product Carbon footprint (CF): A CF focuses on the complete life cycle or the combined impact of all products produced in a given enterprise or organisation. It must include all impacts covered by a CA, and additionally must include scope 3 emissions, including impacts from the production of purchases (for example, fertilisers) and from livestock purchased by the enterprise but bred on other farms. Impacts from a CF are typically reported in kilograms of CO_2-e per kilogram of live weight. Impacts can also be reported in tonnes of CO_2-e for the enterprise but this must differentiate between scope 1, scope 2 and scope 3 emissions. Normative references for carbon footprinting include ISO 14040[1]/44[2], ISO 14067[3] and the LEAP large[4] and small[5] ruminant guidelines.

The document is separated into four sections, i) estimation of livestock related emissions, ii) estimation of emissions from fertiliser and crops, iii) estimation of emissions from purchases, and iv) estimation of emissions or sequestration from vegetation and soil changes (land use and land use change). Other points have been grouped in section v), including matters such as the choice of global warming potential (GWP) values and allocation methods between multiple products.

1. Livestock Emission Sources

National Inventory report (NIR)[6] methods must be applied for:

1. Feed intake,
2. Enteric methane,
3. Manure emissions,
4. Indirect emissions.

[1] ISO, "ISO 14040:2006 - Environmental Management - Life Cycle Assessment - Principles and Framework" (Switzerland: International Organisation for Standardisation (ISO), 2006).
[2] ISO, "ISO 14044:2006 - Environmental Management - Life Cycle Assessment - Requirements and Guidelines" (Switzerland: International Organisation for Standardisation (ISO), 2006).
[3] ISO, "ISO 14067:2018 - Greenhouse Gases - Carbon Footprint of Products - Requirements and Guidelines for Quantification" (Switzerland: International Organisation for Standardisation (ISO), 2018).
[4] LEAP, "Environmental Performance of Large Ruminant Supply Chains: Guidelines for Assessment" (Rome, Italy: Food and Agriculture Organisation of the United Nations (FAO), Livestock Environmental Assessment Program (LEAP), 2015).
[5] LEAP, "Greenhouse Gas Emissions and Fossil Energy Use from Small Ruminant Supply Chains: Guidelines for Assessment" (Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), Livestock Environmental Assessment Program (LEAP), 2016).
[6] Commonwealth of Australia, "National Inventory Report 2017, Volume 1" (Australian Government, Department of the Environment and Energy, 2019).

Non-NIR approved methods may be applied for comparison with justification (for example, based on more recent science).

Activity data: At the farm scale, key activity data must reflect on-farm production rather than regional or NIR defaults. These data should be verifiable.

Key activity data include:

1. Livestock numbers and head days,
2. Livestock weight,
3. Livestock growth rates,
4. Pregnancy/lactation status,
5. Feed intake (feedlots only).

It is acknowledged that for developing rapid CAs, default values may be used. This must be stated. Default values may be taken from the NIR report for the region of interest, or from other published sources.

Examples of activity data that may be sourced from third party sources (i.e. the NIR or reputable research) include:

1. Pasture crude protein,
2. Pasture dry matter digestibility,
3. Manure ash content,
4. Feedlot ration characteristics,
5. Residue mass for estimation of burning emissions (i.e. from crops).

In a CA, impacts must be determined for all livestock on the operation. Production data must be cross-checked with the output from the enterprise (in terms of livestock numbers sold and live weight/wool sold).

In addition to the requirements above for a CA, in a CF the impacts must be determined for all livestock relevant to the life-cycle of the product sold. For traded cattle, this requires assessment of impacts prior to these animals arriving on the farm. Where an enterprise sells large numbers of young livestock (i.e. weaners) this should also be specified in the results because this is an earlier point in the life cycle than when animals are ready for slaughter.

Acknowledging that livestock production is often variable from season to season, a minimum of two production cycles of livestock inventories are required for determining the baseline emissions for a farm.

2. Emissions from Fertiliser and Crops

NIR methods must be applied for:

1. Soil and fertiliser related emissions,
2. Indirect emissions,
3. Residue emissions.

Activity data: At the farm scale, key activity data must reflect on-farm production rather than regional or NIR defaults. These data should be verifiable.

Key activity data include:

1. Hectares grown and crop yield,
2. Mass of N applied as fertiliser,
3. Mass of N applied as purchased manure (i.e. feedlot manure, poultry manure),
4. Other?

Examples of activity data that may be sourced from third party sources (i.e. the NIR or reputable research) include:

1. Residue mass for estimation of burning emissions (i.e. from crops).

3. Emissions from Purchases

1. A CA must include on-farm diesel use and petrol use as scope 1 emissions. Emission factors from the NGERS[7] must be applied.
2. A CA must include scope 2 emissions from electricity use. Emission factors from the NGERS must be applied, for each state or region. If specific power sources are known, these should be used.
3. A CF must include all scope 1, scope 2 and material scope 3 emissions. Scope 1, scope 2 and scope 3 emissions shall be determined using the most suitable background inventory data available.
4. The cut off for materiality with scope 3 emissions excludes impacts from infrastructure and minor veterinary chemicals. Exclusions should be justified and stated.

Activity data: At the farm scale, key activity data must reflect on-farm production rather than regional or NIR defaults. These data should be verifiable.

Key activity data include:

1. Scope 1: diesel use, petrol use,
2. Scope 2: grid electricity use and source,
3. Scope 3: fertiliser, livestock, fodder, grain, supplements etc.

Examples of activity data that may be sourced from third party sources include:

[7] Commonwealth of Australia, "National Greenhouse and Energy Reporting Scheme Measurement Technical Guidelines for the Estimation of Emissions by Facilities in Australia" (Australian Government - Department of Environment and Energy, 2017).

1. Feed grain inputs – may be accessed from the AusLCI[8] database, other reputable databases using Australian emission estimation methods for Australian crops, or country specific published research,
2. Fertilisers – may be accessed from the AusLCI database.

4. Emissions or Sequestration from Vegetation and Soil Changes (Land Use and Land Use Change)

Methods that are not inconsistent with the NIR shall be used. Alternative methods supported by published research may also be used for comparison, or where NIR methods are unavailable. These methods shall be applied for determining all sources of emissions and sequestration associated with land use and land use change (LULUC). Relevant sources included in the minimum standards are outlined in Table **1** – Table 7. An example of how these emission and sequestration sources and sinks would be compiled in a CA is provided in Table 8.

Key points:

- Because all land use and land use change factors are inter-related, one consistent model must be applied that is not inconsistent with the NIR.
- Alternative models may also be applied for comparison, and these must also be internally consistent with respect to the different inter-related emission and sequestration sources.
- Additionally, it is noted that projections related to carbon stock changes should be completed using consistent methods for determination of the carbon balance.

[8] ALCAS, "AusLCI" (Australia: Australian Life Cycle Assessment Society (ALCAS). Available at: http://auslci.com.au/, 2017).

Table 1 – Proposed minimum standards for reporting emissions from grasslands

Category	Included in NIR	Time period (CA)	Time period (CF)	Methods proposed for use in min. standards.	To be included in min. standards?
Soil carbon stocks, Change in soil carbon	Yes	Short term – aligned with assessment (previous 3-6 years)	Previous 20 years	If no change in land use (i.e. grassland remains grassland), it is recommended to assume no change in soil carbon. In addition to the above, further investigation using alternative, scientifically proven models for handling alternative pasture and grazing management may be applied. Future approach: NIR spatial mapping applied to farmland area as the minimum. SA2 level. Represent the national soil grid at property scale? (possibly not yet). In short term – look up soil carbon for relevant region for the farm.	Yes
Sparse woody vegetation stocks, Change in live biomass (sparse woody vegetation <20% canopy cover)	Yes	Short term – aligned with assessment	Previous 20 years	Minimum standard: spatially enabled or farm-based approach to report emission data from NIR spatial layers, at the farm scale. Alternatively, spatially enabled methodologies at the farm scale with site specific inputs that are not inconsistent with the NIR can be applied.	Yes
Sparse woody vegetation DOM stocks, Change in dead organic matter (DOM) (sparse woody vegetation <20% canopy cover)	No	Short term – aligned with assessment	Previous 20 years	Minimum standard: spatially enabled approach to report emission data from NIR spatial layers, at the farm scale. Alternatively, spatially enabled or farm-based methodologies at the farm scale with site specific inputs that are not inconsistent with the NIR can be applied.	Yes

				Note: in the NIR, DOM is included as a flow to soil carbon, but not separately reported). Is assessed in FullCAM.	
Change in grass live biomass	No	Short term might not be meaningful – long term trends are more relevant and important	Short term might not be meaningful – long term trends are more relevant and important	Minimum standard: Spatially enabled or farm-based approach to report emission data from NIR spatial layers, at the farm scale. Alternatively, spatially enabled methodologies at the farm scale with site specific inputs that are not inconsistent with the NIR can be applied. Is determined in the NIR, but not reported. If land management changes, this can be altered and could be substantial. Regional calibrations are being developed currently.	Y (but further consideration is required)
Change in grass dead organic matter (DOM)	No	Short term – aligned with assessment	Short term – aligned with assessment	Assessed as part of the carbon cycle and balance for assessing soil carbon. Not separately reported.	Yes (but further consideration is required)
Managed fire	Yes	Short term – aligned with assessment	Short term – aligned with assessment	Minimum standard: determine area burned and apply NIR default activity data and factors for non-CO_2.	Yes
Wildfire	Yes	NA	NA	Needs to be modelled to understand impacts on vegetation pools, but emissions do not need to be reported. Is reported in the NIR, but it is safe to say it could be excluded at the farm scale because it is not anthropogenic.	No

Table 2 – Proposed minimum standards for reporting emissions from deforestation

Category	Included in NIR	Time period (CA)	Time period (CF)	Methods proposed for use in min. standards.	To be included in min. standards?
Change in soil carbon	Yes	Short term – aligned with assessment	Previous 20 years	Minimum standard: Spatially enabled or farm-based approach to report emission data from NIR spatial layers, at the farm scale. Alternatively, spatially enabled methodologies at the farm scale with site specific inputs that are not inconsistent with the NIR can be applied. Note, soil C losses continue to occur over a period of 20 years and consequently, historic modelling is required.	Yes
Change in live biomass to new land use	Yes	Short term – aligned with assessment	Previous 20 years	Minimum standard: Spatially enabled or farm-based approach to report emission data from NIR spatial layers, at the farm scale. Alternatively, spatially enabled methodologies at the farm scale with site specific inputs that are not inconsistent with the NIR can be applied.	Yes
Change in dead organic matter (DOM) to new land use	Yes	Short term – aligned with assessment	Previous 20 years	Minimum standard: Spatially enabled or farm-based approach to report emission data from NIR spatial layers, at the farm scale. Alternatively, spatially enabled methodologies at the farm scale with site specific inputs that are not inconsistent with the NIR can be applied. Assumptions regarding decomposition/removal rates can be varied where site specific information is available, which is specifically relevant for management practices that don't implicitly involve tree removal (i.e. poisoning, pulling without raking).	Yes
Managed fire	Yes	Short term – aligned with assessment	Previous 20 years	As above (Table 1)	Yes
Wildfire	Yes	NA	NA	As above (Table 1)	No

Table 3 – Proposed minimum standards for reporting emissions from cropland

Category	Included in NIR	Time period (CA)	Time period (CF)	Methods proposed for use in min. standards.	To be included in min. standards?
Change in soil carbon	Yes	Short term – aligned with assessment	Short term – aligned with assessment	If no change in land use (i.e. cropland remains cropland), it is recommended to assume no change in soil carbon. In addition to the above, further investigation using alternative, scientifically proven models for handling alternative crop rotation or tillage management may be applied. Future approach: NIR spatial mapping applied to farm land area as the minimum. SA2 level. Represent the national soil grid at property scale? (possibly not yet). In short term – look up soil carbon for relevant region for the farm.	Yes
Stubble burning				NIR default methods applied to determine non-CO_2 emissions	Yes

Table 4 – Proposed minimum standards for reporting nitrous oxide emissions from managed soils

Category	Included in NIR	Time period (CA)	Time period (CF)	Methods proposed for use in min. standards.	To be included in min. standards?
N mineralisation associated with a change in soil organic matter	Yes	Short term – aligned with assessment	Short term – aligned with assessment	NIR default methods applied	Yes
Leaching and run-off from mineralised N	Yes	Short term – aligned with assessment	Short term – aligned with assessment	NIR default methods applied	Yes

Table 5 – Proposed minimum standards for reporting sequestration in grasslands.

Category	Included in NIR	Time period (CA)	Time period (CF)	Methods proposed for use in min. standards.	To be included in min. standards?
Change in soil carbon	Yes	Short term – aligned with assessment	Previous 20 years	As above (Table 1)	Yes
Change in live biomass (sparse woody vegetation <20% canopy cover)	Yes	Short term – aligned with assessment	Previous 20 years	As above (Table 1)	Yes
Change in dead organic matter (DOM) (sparse woody vegetation <20% canopy cover)	Yes	Short term – aligned with assessment	Previous 20 years	As above (Table 1)	Yes
Change in grass dead organic matter (DOM)	No	Short term – aligned with assessment	Previous 20 years	As above (Table 1)	Yes
Change in grass live biomass	No	Short term – aligned with assessment	Short term – aligned with assessment	As above (Table 1)	Yes

Table 6 – Proposed minimum standards for reporting sequestration via farm forestry, afforestation and reforestation.

Category	Included in NIR	Time period (CA)	Time period (CF)	Methods proposed for use in min. standards.	To be included in min. standards?
Change in soil carbon	Yes	Short term – aligned with assessment	Previous 20 years	Minimum standard: Spatially enabled or farm-based approach to report emission data from NIR spatial layers, at the farm scale. Alternatively, where specific data are available on management, this can be used to develop an improved site assessment using methods not inconsistent with the NIR. Planting and harvest dates, biomass removal (logs) etc. Spatially enabled methodologies at the farm scale with site specific inputs that are not inconsistent with the NIR can be applied. Afforestation and reforestation should be consistent with environmental planting schemes/ERF (Emission Reduction Fund) methods.	Yes
Change in live biomass	Yes	Short term – aligned with assessment	Previous 20 years	Minimum standard: Spatially enabled or farm-based approach to report emission data from NIR spatial layers, at the farm scale. Alternatively, spatially enabled methodologies at the farm scale with site specific inputs that are not inconsistent with the NIR can be applied.	Yes
Change in dead organic matter (DOM)	Yes	Short term – aligned with assessment	Previous 20 years	Minimum standard: Spatially enabled or farm-based approach to report emission data from NIR spatial layers, at the farm scale. Alternatively, spatially enabled methodologies at the farm scale with site specific inputs that are not inconsistent with the NIR can be applied.	Yes

Table 7 – Proposed minimum standards for reporting emissions sequestration in croplands

Category	Included in NIR	Time period (CA)	Time period (CF)	Methods proposed for use in min. standards.	To be included in min. standards?
Change in soil carbon	Yes	Short term – aligned with assessment	Previous 20 years	Minimum standard: Spatially enabled or farm-based approach to report emission data from NIR spatial layers, at the farm scale. Alternatively, where specific data are available on management, this can be used to develop an improved site assessment using methods not inconsistent with the NIR. Planting and harvest dates, biomass removal (logs) etc. Spatially enabled methodologies at the farm scale with site specific inputs that are not inconsistent with the NIR can be applied. Afforestation and reforestation should be consistent with environmental planting schemes/ERF methods.	Yes

At the farm scale, key activity data must reflect on-farm impacts rather than regional or NIR defaults. These data should be verifiable.

Key activity data include:

1. Existing maps (NIR layers, pasture layers). Provide these, then use maps to guide additional information capture.
2. Farm questionnaire including:

   Land Use:
   1. Total land area used
   2. Total crop land area
   3. Total pasture land area suitable for cropping (arable land)
   4. Total land area classified as remnant forest

   Land Use Change – vegetation:

   5. Total land area cleared in the previous 20 years.
   6. Total land area subject to regrowth (i.e. after a clearing event) and when did regrowth commence?

7. Total land area subject to woody thickening and when did woody thickening commence?
8. Area of trees planted, species and year of planting.

Land Use Change – soil carbon

9. Total pasture area converted from cropping to permanent pasture (or vice versa) in the previous 20 years.
10. Other soil carbon related questions?
11. Are soil tests available that provide evidence of soil carbon levels and change over time? If so, please provide.

Managed Fire

12. Area burned as part of routine management?
13. At what time of year were managed fires lit?
14. What land classes were burned?
15. What is the estimated biomass (tonnes dry matter) that were burned?

Table 8 – Chart of accounts for carbon accounting on a beef operation

GHG flux	Sector	Category	Sub-category	Emission scope	Value
Emissions	Agriculture	Livestock emissions	Enteric methane	1	
			Manure	1	
			Indirect manure emissions	1	
		Cropping/pasture	Nitrous oxide emissions – fertiliser	1	
			Nitrous oxide emissions - residue	1	
			Indirect emissions	1	
		Purchases	On-farm fuel use	1,3	
			Grid-supplied electricity	2	
			Fuel use	1, 3	
			Transport of goods to farm	3	
			Other agricultural inputs[1]: livestock, fodder, grain, supplements, etc	3	
	Land use, land use change, forestry	Grasslands	Change in soil carbon	1	
			Change in sparse woody veg. live biomass	1	
			Change in sparse woody veg. DOM [2]	1	
			Change in grass live biomass	1	
			Managed fire	1	
		Forests (deforestation)	Change in soil carbon	1	
			Change in forest live biomass	1	
			Change in forest DOM	1	
			Managed fire	1	
		Croplands	Change in soil carbon	1	
		N_2O from LUC	N mineralisation associated with a change in soil organic matter	1	
			Leaching and run-off from mineralised N	1	
Sub-total emissions					
Sequestration	Land use, land use change, forestry	Grasslands	Change in soil carbon	1	
			Change in sparse woody veg. live biomass	1	
			Change in sparse woody veg. DOM	1	
			Change in grass live biomass	1	
		Farm forestry	Change in soil carbon	1	
			Change in forest live biomass	1	
			Change in forest DOM	1	
		Forests (afforestation, reforestation)	Change in soil carbon	1	
			Change in forest live biomass	1	
			Change in forest DOM	1	
		Croplands	Change in soil carbon	1	
Sub-total sequestration					
Carbon balance					

[1] For consistency, other agricultural inputs need to be modelled using equivalent methods and boundaries.
[2] Dead organic matter

5. Other Issues

Global Warming Potentials

Current NIR report values shall be applied. Methane = 25, nitrous oxide = 298. These values will be updated according to the schedule set by the Dept of Env. Team.

IPCC AR 5 values (methane = 28, nitrous oxide = 265) may be applied for comparison.

Allocation of impacts between multiple products on-farm for reporting carbon footprints

Allocation should follow the basic guidance from ISO 14044, favouring that allocation is first avoided if possible, then achieved on the basis of underlying biophysical properties and principles.

Farms are to be separated into sub-systems and impacts are to be calculated and reported separately for crops, beef and sheep. Overheads are to be divided between subsystems based on the biophysical relationship between the systems. For example, for sheep and beef this can be achieved by dividing on the basis of total feed intake (effectively stocking rate – i.e. dry sheep equivalents). For dividing overheads between cropping and livestock, this can be done on the basis of the total gross value ($) of production from the farm.

With respect to red meat production, the following minimum standards are given:

1. Farm output from livestock must be reported in kilograms or tonnes of live weight or greasy wool. This is because other units (such as carcase weight or clean wool) require further processing and produce additional co-products post farm gate. Reporting using these units overlooks these processes and creates a mismatch between the reporting unit (functional unit or reference flow) and the system boundary.
2. Allocation is not required between live weight from different classes of livestock (i.e. steers vs cull cows). All live weight is to be summed.
3. Allocation between greasy wool and live weight. Proposed method is the ‘protein mass’ allocation method[9] as a simplified biophysical approach.

[9] Stephen G. Wiedemann et al., “Application of Life Cycle Assessment to Sheep Production Systems: Investigating Co-Production of Wool and Meat Using Case Studies from Major Global Producers,” *International Journal of Life Cycle Assessment* 20, no. 4 (2015): 463–76, https://doi.org/10.1007/s11367-015-0849-z.

Appendix 1

This appendix lists the agenda and attendees for two workshops designed to identify the minimum standards required to determine the carbon account and carbon footprint of red meat systems.

Workshop 1 - Carbon account and carbon footprint of red meat systems – Minimum Standards

Attendees: Steven Bray (Queensland Department of Agriculture, Fisheries and Forestry), Simon Clarke (Integrity Ag & Environment), Richard Eckard (University of Melbourne), Doug McNicholl (Meat & Livestock Australia), Shanti Reddy (Department of the Environment and Energy), Rob Sturgiss (Department of the Environment and Energy), Robert Waterworth (Mullion Group), Steve Wiedemann (Integrity Ag & Environment).

Date, time: 12th September 2019, 1 – 4 pm.

Location: MLA offices, North Sydney.

Agenda

Time	Item
1pm	Overview of purpose for developing minimum standards
1.10pm	Review of general principles and reference documents. 1. Not inconsistent with NIR methods 2. Not inconsistent with ISO standards for carbon footprint (14067), carbon accounts (14064) 3. LEAP large ruminant / small ruminant guidelines
1.20pm	Review of livestock emission source methods and activity data requirements
2.30pm	Emissions from fertiliser and crops
2.45pm	Emissions from purchases (scope 2, scope 3) Cut-offs
3.00pm	Other considerations
3.20pm	Vegetation and soil carbon – proposed options.
3.55pm	Summary and next steps
4.00pm	Meeting close

Workshop 2 - Carbon account and carbon footprint of red meat systems – Minimum Standards

Attendees: Steven Bray (Queensland Department of Agriculture, Fisheries and Forestry), Simon Clarke (Integrity Ag & Environment), Richard Eckard (University of Melbourne), Shanti Reddy (Department of the Environment and Energy), Philip Tickle (Cibolabs), Robert Waterworth (Mullion Group), Steve Wiedemann (Integrity Ag & Environment).

Date, time: 26th September 2019, 9 am – 12 pm.

Location: Videoconference.

Agenda

Time	**Item**
9am	Welcome and intro
9.15	What sources of emissions and sequestration should be taken into account?
10.15	What are the preferred methods to account for these?
11.15	What activity data are required (potentially including both Landsat inputs – i.e. property boundaries and farmer questionnaire data)?
11.50	Close and next steps – is another meeting required?