Final report

Simplifying carbon footprint assessments of beef enterprises

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Abstract

There is a need to determine the greenhouse gas (GHG) emissions and sequestration sources of beef-producing farms to help inform farm-level decision making and marketing efforts for low carbon or carbon neutral livestock products. This must be underpinned by a carbon footprint (CF) framework for Australian contexts and methods for efficiently quantifying the CF of beef-producing farms. In response, this project delivered a set of minimum standards providing a systematic approach to the CF process. CF methods compliant with international standards and national GHG reporting were used to determine the CF of seven case study farms. These farms were used to test the sensitivity of the CF to substituting the original data for default regional or state data. The case studies showed the process of providing farm inventory data for a simplified CF assessment can be expedited by providing regional default values for bull inclusion rate and farm purchased inputs (diesel, petrol, superphosphate and lime). Conversely, user-supplied data should be used for herd productivity parameters including cow weight, mortality rate, weaning rate, and age and weight of young cattle at turnoff. The findings promote producer engagement with the concepts of carbon assessment by making the process of determining a CF more practical and efficient.

Executive summary

Background

The red meat industry has an aspirational goal to achieve carbon neutrality by 2030. In response to this there is a growing need to determine the greenhouse gas emissions and sequestration sources of individual beef-producing farms. However, performing a carbon assessment at the farm-scale can be difficult and expensive when scientifically robust methods are used. Currently, one substantial barrier to widespread on-farm carbon assessment is the lack of consensus, and the complicated methods and tools required. There is therefore a need to develop a preferred CF framework for Australian contexts, and to identify methods for efficiently quantifying the CF of beef-producing farms.

Objectives

This project aims to clarify the requirements for an on-farm CF, identify the key components required in CF tools, significantly improve the on-farm knowledge base regarding CF and greenhouse gas (GHG) assessment, and importantly, move towards reducing the complexity and cost of conducting an on-farm CF. The objectives for this project were:

1. Review existing carbon footprint frameworks and key aspects of carbon footprint tools
2. Identify and develop a preferred CF method and framework for producers to determine their CF
3. Complete up to 7 farm case studies, including assessment of baseline emissions, and for selected farms, sensitivity analyses of the impact of changing livestock and pasture type/growth numbers, and high or low rainfall years where data are available.
4. Participate in discussions with farm managers to understand how their current management and proposed business improvement plans will impact on their carbon footprint.
5. Develop a simplified set of data requirements to calculate a farm-scale carbon footprint which can be linked to industry and government reporting via the National GHG Inventory.

As acknowledged at the scoping stage, this project represents an important first step in the process of scaling up CF determinations to a much larger number of farms. Seven case studies will provide important insights, but the results will not be representative across an industry that consists of approximately 48,000 farms (MLA 2018).

Methodology

Methods and tools for determining greenhouse gas emissions from beef production systems were reviewed. A working group was assembled to define a set of minimum standards for determining the CF of a beef and sheep farms, then combined with the review to recommend key carbon footprint framework attributes, methods and data sources to determine the CF of beef production on Australian farms.

Methods consistent with ISO standards and the Australian GHG reporting were used to determine cradle-to-farm gate carbon footprints (including scope 1, 2 and 3 emissions) for beef production on seven case study farms. To examine potential to reduce the size and complexity of the data request, for selected model parameters, regional (or state) defaults values were substituted for case study farm observed values, and the effect of these substitutions on the case study farm CF was assessed.

Results/key findings

The first major output of this project was the development of a common framework and set of minimum standards for determining the CF of beef and sheep farms which have been freely provided to researchers and service providers working on carbon assessments in the Australian red meat industry. These were also used to update the most readily available GHG too – now known as SB-GAF (version 1.3).

The CF of the case study farms was relatively insensitive (< 2 % change at 95 % confidence limits) to default data for farm purchased inputs (i.e. fuel and fertiliser use) and bull inclusion rate, moderately sensitive (≤ 5 %) to some default herd data (weaning rate and cow weight), and highly sensitive (> 5 %) to default herd data on mortality rate and steer weight for age. Errors introduced by substituting individual values for specific parameters were not highly additive because changes brought about by substituting values for some parameters cancelled out changes in others.

Benefits to industry

The minimum standards developed under this project are important for encouraging a systematic approach to the CF process and set the framework upon which industry efforts to achieve carbon neutrality will be assessed.

The present research shows the process of providing inventory data to a simplified CF calculator can be improved by providing regional default values for bull inclusion rate and purchased inputs (diesel, petrol, superphosphate and lime). Conversely, CF calculators would benefit by setting quality control thresholds on user input relating to cow weight, weaning rate, mortality rate and steer weight for age.

Future research and recommendations

Clearly, to provide definitive results a larger dataset would be required to confirm the findings here, and the present results should be viewed with caution because of the relatively small dataset.

The findings of this project should be considered in future industry investments in carbon assessment tools.

A working group should be convened to review and revise the minimum standards developed as part of this research in approximately 18 months' time (end of 2022).

Table of contents

1. Background

The red meat industry has an aspirational goal to achieve carbon neutrality by 2030 (MLA 2017). In response to this there is a growing need to determine the greenhouse gas emissions and sequestration sources of individual beef-producing farms. However, performing a carbon assessment at the farm-scale can be difficult and expensive when scientifically robust methods are used.

Currently, one substantial barrier to widespread on-farm carbon assessment is the complicated methods and tools required for prediction. There are also multiple frameworks that define a 'carbon footprint' (CF) or a 'carbon account', and this variation causes confusion. While there are international standards for carbon footprinting (ISO 2018) the sector-specific guidelines for applying these standards to Australian red meat production don't exist. One gap relates to how the livestock emissions should be determined and what specific methods and calculators should be used to achieve this. There are multiple calculators using different methods to predict livestock emissions, adding to the complexity and potential confusion. Additionally, these were each designed with specific purposes in mind, which may or may not be suitable for determining the CF of beef. This problem is not unique to Australia. The Global Roundtable for Sustainable Beef (GRSB) recently commissioned a review in which global frameworks and methodologies for assessing emissions from beef production were reviewed (McConkey et al. 2019). The major challenge applying international tools, such as those reviewed by GRSB, in an Australian context is remaining consistent with LEAP and IPCC guidelines, which promote the use of the highest tier calculation method, especially in developed nations (IPCC 2006b; LEAP 2015a). The annual Australian National Inventory Reports (NIR) cite the Australian research that underpins the models and factors used to calculated local emissions from beef herds (e.g. Commonwealth of Australia 2020a). International tools used in Australian contexts are unlikely to produce similar results to an NIR-consistent method – their use without an underlying Australian methodology defies convention, and is therefore not recommended. There is therefore a need to develop a preferred CF framework for Australian contexts, and to identify methods for efficiently quantifying the CF of beef-producing farms.

2. Objectives

This project aims to clarify the requirements for an on-farm CF, identify the key components required in CF tools, significantly improve the on-farm knowledge base regarding CF and greenhouse gas (GHG) assessment and offsetting frameworks, and importantly, move towards reducing the complexity and cost of conducting an on-farm CF. The objectives for this project were:

1. Review existing carbon footprint frameworks and key aspects of carbon footprint tools
2. Identify and develop a preferred CF method and framework for producers to determine their CF
3. Complete up to 7 farm case studies, including assessment of baseline emissions, and for selected farms, sensitivity analyses of the impact of changing livestock and pasture type/growth numbers, and high or low rainfall years where data are available.
4. Participate in discussions with farm managers to understand how their current management and proposed business improvement plans will impact on their carbon footprint.

5. Develop a simplified set of data requirements to calculate a farm-scale carbon footprint which can be linked to industry and government reporting via the National GHG Inventory

These objectives were met by performing a literature review of carbon assessment methods and frameworks (objective 1, 2), by convening a working group to develop a set of minimum standards for carbon assessments in beef production systems (obj. 2), by determining the CF of case study farms and substituting their original data on specific inventory items for regional or state default data (obj. 3), by using a simplified data request to generate a CF report (including recommendations for reducing GHG emissions) for 10 producers participating in an allied project (assessing farm sustainability) (obj. 4, 5), and extending the findings of this research to projects that improved a calculator for determining the CF of beef production (MLA project P.PSH.1252) and delivered workshops on carbon assessment to beef producers the (National Landcare Carbon Footprint Project) (obj. 4).

As acknowledged at the scoping stage, this project represents an important first step in the process of scaling up CF determinations to a much larger number of farms. Seven case studies will provide important insights, but the results will not be representative across an industry that consists of approximately 48,000 farms (MLA 2018).

3. Methodology

3.1 Modelling of case study farm footprints

3.1.1 Project Scope

Cradle-to-farm gate carbon footprints (including scope 1, 2 and 3 emissions) were completed for beef production on seven case study farms. This included all GHG emissions and sequestration sources within the operational boundary of the business as well as emissions associated with purchased inputs to the farm.

The case study farms represent a variety of production regions, from the Northern Territory to Victoria, and primarily for the financial years 2018-19 and 2019-20 (Table 1). Much of Queensland, New South Wales, Victoria and South Australia were affected by drought in 2018 and the following year (2019) was the driest on record. These conditions persisted into early 2020 (Bureau of Meteorology 2020). Consequently, many herds were destocking in response to reduced feed availability.

Table 1. Spatial and temporal scope of case study farms

Case study farm no.	State	ABARES* region	Observation period (financial years)
1	Queensland	Darling Downs and Central Highlands of Queensland	2018-19, 2019-20
2	Queensland	Eastern Darling Downs	2018-19, 2019-20
3	New South Wales	Riverina	2018-19, 2019-20
4	Victoria	Central North	2018-19, 2019-20
5		Southern and Eastern Victoria	2018-19, 2019-20
6	New South Wales	Tablelands (Northern Central and Southern)	2015-16, 2016-17, 2017-18
7	Northern Territory	Barkly Tablelands	2017-18, 2018-19

*Australian Bureau of Agricultural and Resource Economics and Sciences

Emission estimates were determined using the AR5 IPCC global warming potential characterisation factors (GWPs) (Myhre et al. 2013) (Table 2). Emissions were reported as carbon dioxide equivalents (CO_2-e). This unit is used to compare emissions from different GHGs based on their global warming potential (GWP) over a specified time period, typically 100 years (GWP_{100}). Greenhouse gas emissions and carbon storage resulting from land use and direct land-use change and land-use change were not directly included in the assessment, because of difficulties in attributing these emissions to cattle compared to other land uses such as sheep or cropping.

Table 2. Global warming potential (GWP_{100}) values relative to CO_2 (Myhre et al. 2013)

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

3.1.2 Inventory data – case study farms

Livestock and purchased input data from at least two financial years were supplied by producers. Livestock data included opening and closing livestock numbers, weights, sale records, purchase records, mortalities and average calving dates. In most cases these data were exported directly from data management programs and/or spreadsheets. Sales, purchases, births, mortalities and change of class for each livestock class were reconciled with opening and closing livestock numbers. Average daily gain and age at sale/slaughter were calculated from sale weights, sale dates and mean calving dates. All data were averaged across two financial years.

Key farm services parameters included energy, purchased feed, fertiliser and other services and farm inputs. These data were extracted from data management program exports and financial records. Only farm services data associated with the production of beef were included in the analysis. Farm services data were also averaged over two financial years.

Farms used in the analysis were located in the Northern Territory, Queensland, New South Wales, and Victoria. As a result of drought across these regions, many enterprises destocked to match feed availability and retained more animals in the years following drought to rebuild their herds. Corrections were made to livestock data to reflect stable herds as most farms had depressed sales in one or both years. Adjustments to livestock numbers were made based on the ratio of sales to births.

Dry matter crude protein was estimated from NIR state by season data (Commonwealth of Australia 2020a). These values were revised upwards to reflect the use of improved pastures or supplementary feeding: for case study 3 (New South wales Riverina) the crude protein content was set to that of Victoria (16.5 %), and the crude protein contents for case studies 2 and 7 were set at 13 and 9 %, respectively, to reflect high protein feed additives.

Inventory data for the case study farms are summarised in Table 3 and Table 4.

Table 3. Cattle production parameters of grass-finished beef from case study farms

Parameter	Values						
Case study farm no.	1	2	3	4	5	6	7
Mean cow weight (kg LW)	460	623	552	573	575	550	481
Cows mated annually	1,547	77	1,594	1,346	658	274	5250
Liveweight sold per year (t LW)	584	194	808	508	325	81	1,663
Feed consumption (t DMI)	8,958	1,660	10,967	8,983	4,495	1616	29,019
Weaning rate (%)	76	80	94	91	93	88	78
Breeder culling rate (%)	15	8	19	9	15	15	11
Mortality rate (%)	0.8	1.2	1.7	3.7	0.9	2.0	2.1
Weaning weight (kg LW)	278	311	312	254	251	215	224
Weaning age (months)	10.0	9.0	8.0	8.0	8.9	6	8.9
Steer sale weight (kg LW)	499	437	576	443	586	402	478
Steer ADG (kg/day)*	0.61	1.06	0.94	0.71	0.79	0.85	0.70
Heifer sale weight (kg LW)	447	408	454	383	411	359	325
Heifer ADG (kg/day)*	0.58	0.99	0.73	0.57	0.57	0.90	0.46
Purchased cattle (number of head)	0	382	0	0	97	0	0
Purchased cattle mean weight (kg LW)	0	240	0	0	300	0	0

*Lifetime ADG

Table 4. Farm services reported per tonne of dry matter intake (DMI) for case study farms

Category	Parameter	Values						
Case study farm no.		1	2	3	4	5	6	7
Energy	Electricity (kWh/t DMI)	1.8	1.5	2.6	1.3	2.7	0.0 [1]	0.0 [1]
	Diesel (L/t DMI)	5.9	4.0	5.4	2.3	4.2	8.2	5.8
	Petrol (L/t DMI)	0.3	0.0	0.3	0.4	0.6	1.5	3.3
Purchased feed	Feed supplements (kg/t DMI)	1.4	0	14.5	0.0	36.2	1.2	4.5
	Hay (kg/t DMI)	0.7	132.1	124.7	14.5	0.0	0.0	0.0
	Grain (kg/t DMI)	1.2	249.8	6.3	0.0	0.0	0.0	0.0
	Forage crops (kg/t DMI)	0.0	43.2	25.2	0.0	0.0	198.0	0.0
Fertiliser	Super phosphate (kg/t DMI)	0.0	0.0	12.2	14.5	20.3	5.0	0.0
	Other fertilisers (e.g. urea, MAP) (kg/t DMI)	0.0	0.0	12.8	5.7	14.3	0.0	0.0
	Lime (kg/t DMI)	0.0	0.0	7.8	15.0	51.9	30.9	0.0
Other inputs and services	Veterinary products ($/t DMI)	1.4	7.5	6.9	11.7	8.3	1.1	0.0

[1] Negligible due to use of solar power (case study farm 6) or diesel (case study farm 7).

3.1.3 Allocation of impacts to co-products

There are several points in the production system where co-products were produced. This study follows the methods outlined in Wiedemann, Henry, *et al.* (2015) and Wiedemann, McGahan, Murphy, and Yan (2015) to divide burdens between sub-systems at the farm-scale. Where beef, sheep and cereals were co-produced on the same farm, inputs associated with cropping were first deducted based on the area of crop land sown annually. Inputs associated with sheep and cattle were then divided based on the stocking rate of each, expressed per dry sheep equivalent mass. Manure nutrients from the grazing herd were assumed to return directly to pasture and were therefore considered a biological feedback loop without the need for allocation. Within the cattle production system, we did not differentiate between live weight from young cattle or from cull breeding animals. Impacts were reported per kilogram of beef from the herd.

3.1.4 Greenhouse gas estimation

Greenhouse gas emissions were modelled for livestock (enteric methane and manure emissions) and for purchased inputs (fuel, electricity, feed, purchased cattle etc.) for each case study farm. This study conducted livestock GHG emission modelling according to life cycle assessment (LCA) practices published in the peer-reviewed literature for grazing systems (Wiedemann, McGahan, Murphy & Yan 2015). The methods are compliant with the international guidance for conducting livestock LCA (FAO 2016). Feed intake, enteric methane and manure emissions were determined using methods consistent with the NIR (Commonwealth of Australia 2020a). Inventory data related to dietary crude protein and dry matter digestibility, used in estimation of manure emissions, used regional assumptions from the NIR (Commonwealth of Australia 2020a).

3.1.5 Substituting regional default values

To investigate the potential for simplifying the data requirements, ABARES data for 'specialist beef farms' (ABARES 2020) were used to directly obtain or to derive representative values per region. For selected model parameters, these regional defaults were substituted for case study farm observed values (Table 5). ABARES surveys a sample of farms per region (along with the estimated number of farms per region) and reports these values per financial year. Default values for cow weight were obtained at a state level from slaughter data reported by the ABS (Australian Bureau of Statistics) (Table 5). The default values used in the NIR (Commonwealth of Australia 2020a) for cow weight (minimum value across the seasons for cows > 3 years in the Northern Territory and Queensland, and cows > 2 years in the other states, due to the NIR data structure), and steer weight for age (averaged across the seasons and lifetime) were also used as substitutes for observed values. To keep some of these substitutions realistic, for case study 7 steer weight for age was modelled across the Northern Territory and Queensland, and all NIR cow and steer data for Queensland were chosen from the moderate-high productivity subset of the NIR data for this state.

In addition to the above, three combinations of substitutions were also considered:

- All fertilisers (single superphosphate, urea, lime), all petroleum products (diesel, petrol, oil), and bull inclusion rate (which tended to be conservative). This set was referred to as 'Bull inclusion rate, fertiliser, fuels'.
- All ABARES-derived data (i.e. the above plus weaning rate, mortality rate and cow weight)
- All NIR data (mean cow weight and steer weight for age)

The aim of including these combinations was to assess the effect of simultaneously substituting multiple default values for original values.

The values used as substitutes for original values are presented in Table 6.

Case study farm 6 was analysed separately as part of the scoping stage of the project in which the effect of substituting state default values for farm services (i.e. primarily on-farm fuel and energy use) and herd parameters (bull inclusion rate, replacement heifers/bulls, and average cow weight) were analysed. These results are considered when interpreting results for the other six case study farms (Section 4.5).

Table 5. Summary of default parameters and their information sources used to simplify beef carbon footprint assessments

Parameter group	Source terminology	Model parameter	Classification level	Source
Herd production	Beef bulls at June 30/Beef cows at June 30	Bull inclusion rate	Region	ABARES (2020)
	Beef cattle branding rate	Weaning rate	Region	ABARES (2020)
	Cattle death rate	Mortality rate	Region	ABARES (2020)
	NA – derived	Mean cow weight	State *	ABS slaughter (ABS 2020b) and head numbers (ABS 2020a), informed by male:female carcass weight data of Wilson et al. (2020) and assuming a dressing percent of 0.52.
	Cow standard reference weight	Mean cow weight	State or region where available	NIR (Commonwealth of Australia 2020a)
	Steer liveweight gain	Steer weight for age	State or region where available	NIR (Commonwealth of Australia 2020a)
Farm services	Fuel, oil and lubricants †	Fuel	Region	ABARES (2020)
	Fertiliser §	Superphosphate	Region	ABARES (2020)
	Fertiliser §	Urea	Region	ABARES (2020)
	Fertiliser §	Lime	Region	ABARES (2020)

* In the absence of data for the Northern Territory, Queensland values were used

† Fuel, oil and lubricants for specialist beef farms minus fuel, oil and lubricant expenses for cropping, allocated 70:2:28 to diesel:oil:petrol, respectively (Wiedemann et al. 2016), apportioned between sheep and beef according to DMI, and converted to litres using densities of 0.885, 0.865 and 0.74 kg/L for diesel, oil and petrol, respectively.

§ Fertiliser expenses after accounting for crop fertiliser expenses, apportioned to sheep and beef according to DMI, allocated 15:14:68:3 to urea, MAP, superphosphate and lime based on average values (Wiedemann et al. 2016), and converted to units of mass using ABARES historic data on fertiliser prices.

Table 6. Default values substituted for original values for herd and farm service parameters of case study farms

Parameter group	Parameter	Farm 1		Farm 2		Farm 3		Farm 4		Farm 5		Farm 7	
		Orig.*	Sub.†	Orig.	Sub.	Orig.	Sub.	Orig.	Sub.	Orig.	Sub.	Orig.	Sub.
Herd production	Bull inclusion rate (%)	3.6	4.8	1.3	5.6	2.3	6.2	3.9	3.6	3.0	5.0	5.2	3.8
	Weaning rate (%)	76	79	80	83	94	90	91	69	93	92	78	74
	Mortality rate (%)	0.8	1.6	1.2	3.0	1.7	1.1	3.7	6.0	0.9	2.3	2.1	3.2
	Mean cow weight (kg) (ABS)	460	494	623	494	552	473	573	423	575	423	481	507
	Mean cow weight (kg) (NIR)	460	467	623	467	552	430	573	450	575	450	481	430
	Steer weight for age (kg/d) ††	0.63	0.43	1.06	0.43	0.94	0.47	0.71	0.49	0.79	0.49	0.70	0.47
Farm services	Diesel (L)	54,010	64,141	6,650	3,093	59,709	82,327	21,000	27,759	18,896	27,872	169,407	125,853
	Petrol (L)	2,451	15,789	0	761	3,000	22,938	3,780	6,833	2,752	7,785	6,352	34,509
	Superphosphate (t)	0.0	388	0.0	81.4	133.5	536.6	130.0	141.9	91.2	129.1	0.0	0.0
	Urea (t)	0.0	38	0.0	8.0	80.6	53.3	51.0	14.1	64.3	12.8	0.0	0.0
	Lime (t)	0.0	105	0.0	21.3	85.8	145.8	0.0	38.4	0.0	35.0	0.0	0.0

* Orig. = original value

† Sub. = default value substituted

†† Steer weight for age values are lifetime, not observation period

4. Results

4.1 Review of carbon assessment methods and frameworks

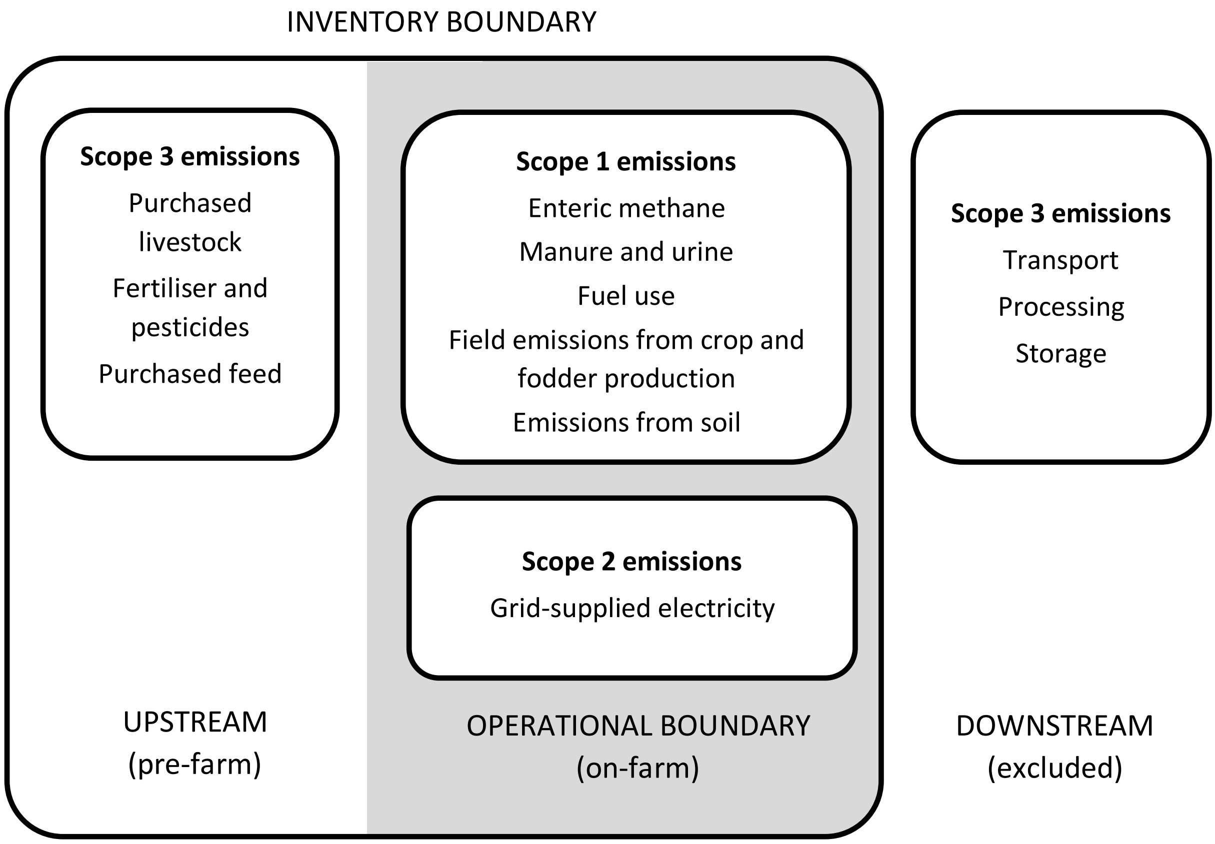
4.1.1 Carbon accounting frameworks

Carbon Accounts

A carbon account is a record of GHG emissions emitted and sequestered within the organisational and operational boundary of an entity, typically expressed in the mass of carbon dioxide equivalent units (e.g. t CO_2-e) emitted. For the operation scale, methods for constructing and reporting GHG inventories are formally described in ISO 14064-1 (ISO 2012).

The carbon account of a beef producing operation will vary depending on the complexity of the operation. Standard protocol is to report emissions with respect to their *scope*, which classifies emissions according to their source (WRI/WBCSD 2007) (Figure 1). Scope 1 emissions are directly under the control of a beef operation (e.g. enteric methane and diesel used in machinery operations), scope 2 emissions result from direct purchased electricity, and scope 3 emissions occur up- or downstream in an operation value chain (e.g. purchased agrichemicals or livestock, or transport of goods to and from the farm). Scope 1 and 2 emissions are more easily defined than scope 3. Reflecting this, reporting of scope 3 emissions is optional (ISO 2012), despite their potentially large contribution to total emissions.

Figure 1 – Emission scopes in relation to the operational boundary of a cradle to gate beef operation including example emission sources.



Carbon Footprints

A product carbon footprint is the amount of GHG emissions released into the atmosphere relative to the functional unit of a product, across the product life cycle, including all impacts from raw material extraction, through to processing, distribution, use and end-of-life stages. Impacts can also be reported as an operation carbon footprint (oCF), which is a sum of all CF impacts across an operation. A CF includes impacts covered by a carbon account, as well as scope 3 emissions. The CF of a product has been defined by PAS 2050 (BSI 2011) and by ISO 14067 (ISO 2018). Both these standards utilise the life cycle assessment (LCA) approach, and use ISO 14040 and 14044 as the normative references for carbon footprinting (ISO 2006a; ISO 2006b). Another way to understand carbon footprinting is to define this as an LCA specific to GHG emissions: a conventional LCA may include multiple impact categories, such as water and fossil fuel use, as well as GHG emissions, and are associated with overarching international standards (ISO 2006a; ISO 2006b). Thus, carbon footprinting has a well-defined research framework. One key innovation with carbon footprinting and LCA was reporting impacts relative to output (defined by the functional unit of the system), thereby linking productivity and environmental outcomes: a lower CF can be achieved by increasing production efficiency, and/or by changing the production process to reduce emissions. With respect to specific guidance around carbon footprinting for beef, additional insight and guidance has been provided by the Livestock Environmental Assessment and Performance Partnership (LEAP) guidelines for life cycle assessment (LCA) in large ruminant systems (LEAP 2015a).

In the case of beef farms, the typical functional unit is one kilogram of beef. Functional units must be consistent if a comparison is done between product systems and may differ according to the goal of the CF study. For example, there may be a need to express the CF of beef production in mass of protein if a comparison is being made with alternative production systems (e.g. legume cropping) supplying protein for human consumption. For primary industries such as the livestock industry, the CF is often reported only for the primary production stage, extending from 'cradle to farm gate', thereby excluding downstream life cycle stages (e.g. transport, meat processing, storage) (Figure 1). The appropriate alignment of system boundary and functional unit requires that studies using a 'cradle-to-farm gate' assessment apply a functional unit of liveweight (LW) (i.e. kg CO_2-e kg LW^{-1}) (LEAP 2015a).

4.1.2 Carbon accounting in beef systems

National Accounts

The Australian federal Department of the Environment and Energy publishes Australia's National Greenhouse Accounts. These accounts include a series of documents that summarise emissions quarterly, by state and territory, by economic sector, and in the form of a National Inventory Report (NIR). As a signatory, Australia is required to submit an annual national greenhouse gas inventory (NGGI) to the United Nations Framework Convention on Climate Change (UNFCCC). The NIR is an important document because it outlines at a national level, GHG emissions and removals. For example, in 2017, Australia's total GHG emissions were 534.7 million t CO_2-e, and 13.2 % of these emissions were from the agriculture sector. Of agricultural emissions, 70.6 % were from enteric methane, which represents 9.6 % of the national emissions (Commonwealth of Australia 2019a).

Under the UNFCCC, there are five sectors that must report their GHG emissions: energy, industry, waste, agriculture and land-use/land-use change/forestry (LULUCF). In the Australian context, the first three report their emissions to the National Greenhouse and Energy Reporting Scheme (NGERS), which mandates corporations to report GHG emissions and/or energy consumption/production when these exceed specified thresholds. For GHG emissions, the current thresholds are 50 kt CO_2-e for corporations, and 25 kt CO_2-e for 'facilities' (i.e. a single undertaking within an industry sector). As an example, several large meat processors were on the 2017-18 NGERS registry. Emissions from the agriculture and LULUCF sector are captured in the National Greenhouse Accounts (NGA). For agriculture, the NGA reports methane and nitrous oxide emissions from (1) enteric fermentation, (2) manure management, (3) agricultural soils, and (4) field burning of agricultural residues, as well as carbon dioxide emissions from urea and lime. The NGERS and NGA are compiled in the Australian Greenhouse Emissions Information System, and data from this system forms the basis of the NIR. The reporting requirements therefore target the most important emission sources, and are subject to rules that determine what emission and sequestration sources are included or excluded. Being a national scale inventory, it does not include impacts associated with imported products, and does not attribute emissions to the industries that 'cause' the emissions. For example, energy emissions are not attributed to any particular energy user. Thus, the national account does not provide industry-specific accounting.

The IPCC publishes guidance for countries to estimate their GHG inventories when reporting to the UNFCCC (IPCC 2003). The IPCC describes methods at three different levels of detail, called tiers. Tier 1 methods require the least information and are of the lowest analytical complexity: they rely on simplifying assumptions, default emission factors and other parameters provided by the IPCC. Tier 2 methods differ from tier 1 primarily in terms of country-specific emission factors and parameters more appropriate to the local environment and management factors. Tier 3 methods use more complex measurements and analyses (e.g. observations of land use over time, seasonally changing parameters) to reduce the uncertainty in GHG. The NIR reports the tiers used to determine GHG emissions. For example, the enteric methane data referred to above was determined using country-specific methods and emission factors for cattle, sheep and pigs, classifying them as tier 2, in combination with tier 1 methods for other large domestic animals (e.g. buffalo, goats, horses, etc.).

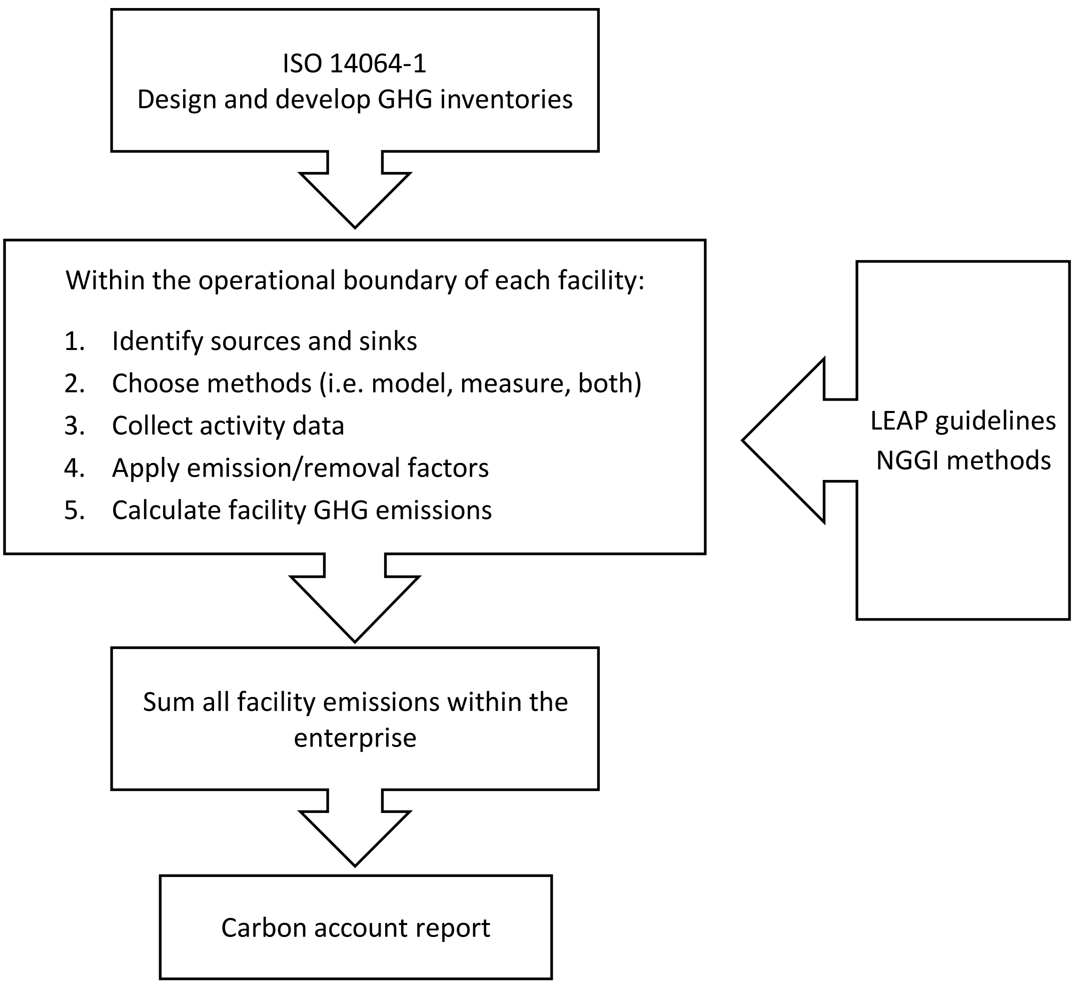
Regardless of the tier used, country-specific activity data are needed. Activity data are quantitative estimates or measures of human activity resulting in emissions or removals for a defined period. The IPCC publishes industry-specific guidelines to help countries develop their national inventory. For example, the guidelines to estimate emissions from livestock and manure management identify a long list of activity data, beginning with livestock species and categories, their populations, through to more detailed information such as average feed intake, fraction of feed converted into methane, weight and weight gain and number of offspring (Dong et al. 2006). In Australia, activity data for the agriculture sector come from the Australian Bureau of Statistics (ABS), the Australian Bureau of Agricultural and Resource Economics (ABARES) and state agencies (Commonwealth of Australia 2020a). Activity data also come from remotely sensed spatial data that is analysed in the FullCAM forestry, agriculture and soil sub-models (Commonwealth of Australia 2020b).

Business Scale Accounts

Carbon accounts can be constructed at a variety of scales, including both operation and national scales. Conceptually, aspects of the beef livestock model applied at the national scale should be similar to that applied at the operation scale. That is, the national herd should theoretically be modelled like a farm, with population dynamics driven by births, deaths (mortality and slaughter) and exports, for example. However, in practice the spatial and temporal resolution of activity data determines the coarseness of models and their factors. The seasonal and regional assumptions used to populate the national accounts lack the specificity needed to accurately determine the carbon account at the scale of a beef operation: that is, there is a greater expectation that tier 3 methods and operation-specific activity data will be used for business scale carbon accounting. Acquiring operation-specific data should not pose a challenge because the most important data, such as head number and liveweights in and out, are central metrics in the production system.

As mentioned above, the international standard for organisation-scale carbon accounting is provided by ISO 14064-1 (ISO 2012). The standard outlines the principles and requirements for designing, developing, managing and reporting organisation-scale GHG inventories, referred to here as a carbon account. Like a CF assessment, the carbon account includes GHG removals, which in beef systems are likely to take the form of carbon sequestration in vegetation or soils. The LEAP guidelines for CF in large ruminant production systems, along with NIR methods, are the publications most relevant to modelling and measuring emissions in beef production systems. Thus, there is a strong methodological link between a carbon account and a CF. The carbon account for an enterprise is the sum of GHG emissions/removals for all facilities within that enterprise (Figure 2). In the context of beef production systems, facilities are discrete farm operations, and those jointly owned comprise an enterprise.

Figure 2 – Relationship of documents and standards to carbon accounting of beef production systems (modified from ISO 2012)**.**



4.1.3 Carbon footprinting in beef systems

The process of conducting a CF in beef systems is summarised diagrammatically below (**Figure 3**). The process consists of four major phases; (1) goal and scope definition, (2) inventory collation, (3) impact assessment, and (4) interpretation (ISO 2006b; LEAP 2015a). The principle references for the beef operations are industry-generic standards (ISO 14040, 14044, 14067), and the LEAP large ruminant industry-specific guidelines (LEAP 2015a).

Goal and Scope Definition

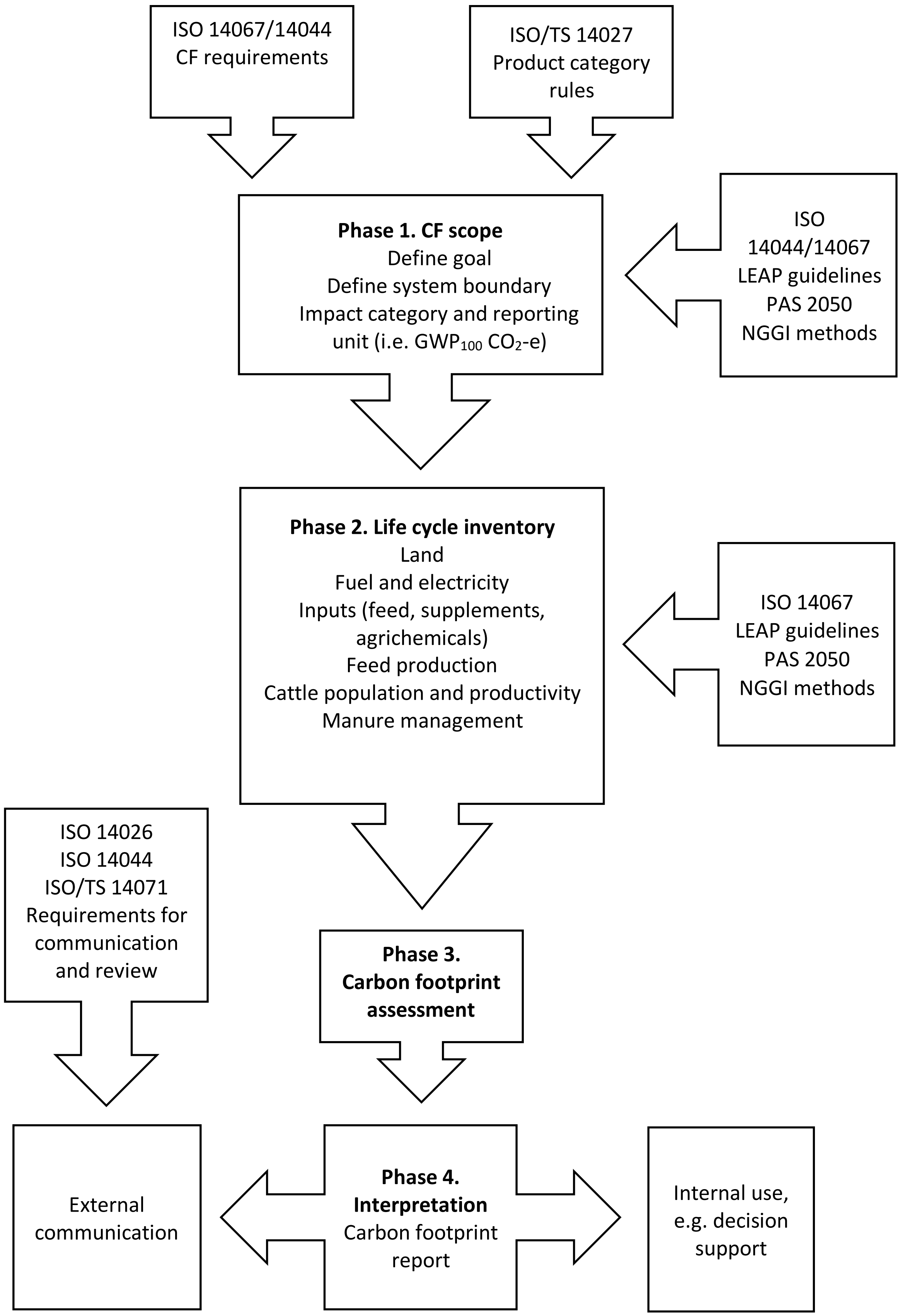
A CF requires a clear purpose to align aims, methods and results. For example, a hotspot analysis requires less rigor than a fully quantitative study used for reporting (LEAP 2015a). A CF is concerned with all GHG that may contribute to global warming: in agricultural contexts, these are commonly methane, nitrous oxide and carbon dioxide. The emission of gases other than carbon dioxide are converted to carbon dioxide equivalents based on their global warming potential (GWP). The GWP values are subject to revision by the IPCC, thus it is appropriate to state the set of GWPs used to determine carbon dioxide equivalence.

As mentioned above, a CF quantifies GHG emissions released into the atmosphere per functional unit, which in the context of beef systems, is likely to be one kilogram of beef (liveweight). Other functional units are possible depending on the boundary of the system: carcass-weight (perhaps including offal, with/without bone) and retail-ready meat are relevant to meat processing and the retail industries, respectively. Thus, the boundary of the system being analysed should be clearly defined, as well as the appropriate functional unit (**Figure 3**). Functional units must be defined and measurable as defined in ISO 14044 (2006b), and guidance on the goal, scope and boundary of the CF assessment up to the meat processing stage are provided by LEAP (2015a). There are post-primary processing product category rules for meat: these conform with ISO/TS 14027 (**Figure 3**) but are beyond the scope of this review.

Inventory Collation

The scale and intensity of data collation may vary from individual farms, to multi-farm operations and state or national sector levels. The information source will reflect this scale, and thus range from farm accounts to government statistics. ISO 14067 (ISO 2018) states that where processes within the lifecycle of a product vary over time, the data should be collected over a period sufficient to establish an average CF. In beef systems, the time boundary should be a minimum of 12 months, and the study must use an 'equilibrium population' required to produce the given mass of product: an average of three to five years is commonly used to account for non-static production and herd inventories (LEAP 2016). Guidelines on how representative and rigorous inventories should be are provided by ISO 14044 and LEAP (ISO 2006b; LEAP 2015a). For beef systems, the LEAP guidelines (LEAP 2015a) collate the most important IPCC (2006a) calculations required to determine emissions from (1) enteric methane, and (2) methane from manure and urine, and (3) nitrous oxide from manure and urine. These are important features of CF models for beef operations.

Figure 3 – Relationship of documents and standards to life cycle assessment of beef production systems (modified from ISO 2018)



A CF assessment may be a more iterative process than implied here (Fig. 3). To rationalise inventory collation, which requires a large amount of data and quality control, a scoping study may be conducted to identify the relative contributions of processes to the CF, and a cut-off used to exclude minor processes from the inventory and evaluation (ISO 2006b; LEAP 2015a).

An important step in inventory collation is life cycle inventory analysis. This is particularly important in beef production systems where uncertainty may exist in important variables such as head number and head days due to the turnover of cattle and the large temporal and spatial scales over which production takes place. An inventory supported by on-farm record keeping should reconcile to produce herd productivity parameters such as average daily gain (ADG) that are biologically plausible and typical for the region and class of cattle.

Impact Assessment

Although there is no single proscriptive method for conducting a CF, the integrated modelling and database software platform required means a limited number of platforms are used. These platforms are not ‘black boxes’ – the assessment technique is open to the inclusion of new scientific findings and users may invest significant intellectual property in model development. LCA software programs such as SimaPro use models of processes and databases (e.g. Ecoinvent) that are valuable repositories of secondary data, that is, indirect measurements used when primary data is not available or impractical to obtain (BSI 2011).

Multifunctionality

ISO 14044 (2006b) provides standard procedures for allocating impacts between co-products and extensive guidance is provided by LEAP (2015a). The best example of this in ruminant systems is sheep meat and wool, both derived from a flock of sheep, usually from the same animal. Other examples include a dairy cattle herd, where meat and milk are outputs from the system, or a beef system, where hides and meat are dual outputs. This review conceptualises beef operations producing a single product at the farm gate; viz, liveweight. However, it is not unexpected for an operation to include a cropping sub-system or a sheep sub-system. these sub-systems are typically handled by separating the sub-systems so that impacts specific to each are attributed to the output of that sub-system. However, where farm overheads (such as fuel use) are used across all sub-systems, these must be allocated and this can be done using a biophysical approach (such as the land required for each sub-system) or the economic value of each sub-system relative to the total.

Carbon Offsets

According to ISO 14067, carbon offsetting is a mechanism for compensating all or part of a CF by preventing, reducing or removing GHG emissions in a product system external to that defined in the CF goal and scope (ISO 2018). There is some debate regarding whether certain sources of carbon emissions or sequestration are directly related to a product system, or are endemic to the natural system within which the beef production occurs. For example, savanna burning emissions may arise from a beef operation in response to a natural event (i.e. a wildfire started by lightning) which would not typically be attributed to the beef product system (Wiedemann, Henry, McGahan, Grant, Murphy, et al. 2015). In a beef operation, sequestration of carbon in trees is within the operational boundary of the production system, but it has been argued whether tree growth is attributable to the beef product. Here we contest that where vegetation growth is directly managed by the livestock producer, the causal association between the product and the vegetation is via the farm management, and is therefore part of the product system. Carbon sequestered by this vegetation will therefore reduce the CF.

4.1.4 Methods for generating carbon credits

In the Australian context, government incentives to sequester carbon in vegetation exist in the form of Emission Reduction Fund (ERF) projects. The ERF is managed by the Department of Environment and Energy and the Clean Energy Regulator, which administers the ERF. The ERF methods, while focused on sequestration or emission reduction, provide important methodological guidance around accounting for various processes relevant to the carbon account/CF of beef. Of relevance is the verification processes used in these methods, which give guidance to development of carbon account/CF that have enough detail to be audited.

Under diverse vegetation management ERF projects, landholders can earn Australian Carbon Credit Units (ACCUs) for not clearing, for planting, or for managing vegetation. Examples of projects that avoid clearing include ‘Avoided clearing of native regrowth’ and ‘Avoided deforestation’. The requirements vary between these projects: the former requires FullCAM modelling and records of disturbances such as fire and thinning, and the latter requires reporting of biomass estimates derived from allometric equations with inputs such as tree height and diameter. ERF projects involving plantation forestry include both model- (i.e. FullCAM) and measurement- (allometry) based approaches, whereas ERF reforestation and afforestation projects are based on extrapolations from sample measurements of multiple forest strata and components (e.g. live/dead trees, leaf litter, fallen dead wood). Like the avoided clearing projects, these require records of disturbances such as fire and biomass removal (on-farm and non-commercial use only; thinning is allowed for ecological purposes only). Projects involving vegetation management relate to forest regeneration from practice change and to generating native forest from managed regrowth. All vegetation methods require mapping, partly to express area-based measurements and model results to a whole-farm scale, but also to demarcate project boundaries and the vegetation distribution at project commencement. Maps are particularly important to the vegetation management projects because they are evaluated on the attainment of forest cover as observed on satellite imagery used to compile the NIR (or similar approved methods).

There is a measurement-based ERF project for soil carbon sequestration that is applicable to land used for cropping, grazing and/or woody horticultural over the last decade. The method involves soil-sampling to measure the baseline soil carbon concentration, implementation of an eligible management activity, and the issue of ACCUs based on increases in soil carbon in subsequent reporting periods (less emissions resulting from the method used, such as livestock grazing and fertiliser application).

Importantly, there are two ERF projects for which beef operations can earn ACCUs that relate to processes directly related to beef production systems. These ERF projects relate to beef herd management, and the use of nitrate lick blocks. For example, at the time of writing, Paraway Pastoral has used an ERF Beef Herd Management project to generate carbon credits that were purchased by the Clean Energy Regulator (Carbon Market Institute 2019). The beef herd management method centres on the use of a spreadsheet calculator (Section 4.1.6), and the nitrate lick block method aims to reduce enteric methane emissions by incentivising the replacement of urea lick blocks.

To summarise, engaging with ERF projects present multiple benefits: in the form of tradeable ACCUs, and the implementation of strategies that should contribute to lowering the emission intensity of the operation, potentially by increasing production efficiency. Each ERF method involves the implementation of an eligible activity, and has a set of auditable rules and methods that must be followed to verify the emission reductions inferred from measurements and/or modelling are real. Issuers of carbon credits other than the Australian government include independent organisations (Gold Standard and Verra), as well as units issued by the UNFCCC that can be obtained by supporting emission-reduction programs in developing countries.

4.1.5 Review of international methods and tools

Global Roundtable for Sustainable Beef findings

A global review of GHG calculators and tools was recently completed for the GRSB (McConkey et al. 2019). This report reviewed six calculators and tools: the Bord Bia Carbon Footprint Model (Ireland), Cool Farm Tool v2.0 (global), CAP 2'ER (France), FAO GLEAM (global), EMBRAPA Carbon Neutral Brazilian Beef Assessment Summary (Brazil), and Bovid CO2 Assessment Summary (principally Spain). Their principal findings were:

1. A review of tools and calculators is not complete without considering the LCI databases that underpin the tools. Of particular concern were inconsistencies in system boundaries between and within databases, particularly with respect to upstream products (p. 47).
2. There is a need to uniformly include soil carbon sequestration in GHG tools and calculators given the potential for large volumes of carbon sequestration and the role of the beef production industry in managing these landscapes (p. 72).
3. There is a scope for improved consistency in many areas, including GWP values, conformity to ISO guidelines for transparency in methodology and demonstrable reproducibility, segregation of beef herds into classes, feed scope 3 emissions and feed quality, functional unit (with LW or LW gain at the farm gate seen as most appropriate), system boundary and allocation of impacts to co-products (pp. 74 – 78).

The major challenge applying international tools, such as those reviewed by GRSB, in an Australian context is remaining consistent with LEAP and IPCC guidelines, which promote the use of the highest tier calculation method, especially in developed nations (IPCC 2006a; LEAP 2015a). The NIR cites the Australian research that underpins the models and factors used to calculated local emissions from beef herds. International tools used in Australian contexts are unlikely to produce similar results to an NIR-consistent method, their use without an underlying Australian methodology defies convention, and is therefore not recommended.

A further challenge is identifying a tool for carbon assessment that includes the requirements for a CF as outlined in the ISO and LEAP guidelines. That is, inclusion of scope 1, 2 and 3 emissions. Of those reviewed, few included all pre-farm (scope 3) emission sources (Table 8): of those that partly reported these emissions, all omitted pre-farm emissions from purchased livestock. This limitation can be circumvented by modelling the purchases as if they were residents within the breeding herd, but the degree to which this is satisfactory will depend on how typical the performance of the breeding herd is, and the importance (or otherwise) of determining gross emissions that are reflective of farm production. Excluding impacts from purchased cattle is not insignificant: where cattle are bought and sold by an operation such as a feedlot, a large proportion of the emissions arise prior to the operational boundary of the feedlot because they are associated with breeding the feeder cattle. It is mandatory in carbon footprinting to include these impacts, though a carbon account for the operation including only scope 1 and 2 emissions may exclude them. As shown in Section 5, this can result in the CF (i.e. scope 1, 2 and 3 emissions) of an operation being more than double the carbon account (scope 1 and 2 emissions only). Guidance with respect to carbon footprinting is clear: emissions associated with breeding and growing traded cattle that are purchased by a farm must be included in the CF of the operation to comply with the cradle-to-farm gate scope of CF in beef production systems (Section 4.1.3). This task is accomplished in CF assessment with the use of LCI databases and models, though in operations that principally trade cattle, the resultant CF will become increasingly dependent on non-specific data and results, reducing data quality.

European Union Product Environmental Footprint Category Rules

The European Livestock and Meat Trades Union recently developed a Product Environmental Footprint Category Rules document for red meat (UECBV 2019). The guidelines are important because they are compliant (with few exceptions) with drafting of European Union product environmental footprint category rules (PEFCRs). PEFCR provide life cycle-based rules to determine the environmental impact of specific products. It is possible that Australian beef producers will need to comply with PEFCRs where this product is to be sold in the EU market. It is therefore important that the CF of Australian beef bound for export to the EU be compliant with PEFCRs.

The key framework elements as they relate to carbon footprinting are outlined below (Table 7). There are three major contrasts with a methodology that would be consistent with the NIR. The first of these is a contrast in GWP, whereby the methane conversion factor for carbon dioxide equivalence is 21 % higher than that used in the NIR. Second, NIR methods for calculating emissions from major sources are country-specific, which is acceptable by the UECBV, but they are tier 2, and therefore not sufficiently sophisticated according to the framework. Third, the framework recommends at least 75 % of emissions associated with the 'digestion of feed, housing and manure storage' (identified as emission hotspots) must come from sources defined by primary data, else conducting the CF assessment 'is not possible'. This has important implications for Australian beef operations that purchase large numbers of livestock, as primary data would be required for purchased cattle if they contributed more than 25% of the emission profile for the farm or supply chain. Ways to satisfy this primary data criterion include (1) development of a recording system that allows primary data to be provided to cattle purchasers at the point of sale, or (2) minimising cattle purchases to less than 25% of the emission profile. Enteric methane emissions are driven by feed intake, so on-farm- relative to lifetime-feed intake would provide a simple proxy for estimating compliance with the UECBV primary data requirement.

Table 7 – Key framework elements for an operation-based beef carbon footprint according to the red meat Product Environmental Footprint Category Rules

Item	Recommended value, method or source	Reference
Functional unit	One tonne of fresh beef including inedible animal parts (such as bone).	
Global warming potential (GWP) factors	IPCC 100-year (34 for CH_4, 298 for N_2O) [1]	IPCC (2013); Fazio et al. (2018)
Calculation methods	IPCC preferred, but country-specific tier 3 methods used in NGGI considered an alternative [2]	
Operation boundary	Cradle to processor gate (guideline focus terminates at the sale of red meat)	Dong et al. (2006)
Temporal boundary	Three years [3]	
Emission sources included	Scope 1, 2 and pre-farm scope 3	
Primary data requirements	A minimum of 75 % of emissions rely on primary data	
Land use and land use change emissions and sequestration	Amortisation period not specified, but impacts to be reported *without*, and possibly *with*, carbon sequestration	
Separating impacts between farm sub-systems	Allocated on a biophysical basis according to energy requirements	UECBV (2019)
Co-production	Consideration given to manure as a co-product	
Herd structure	Not explicit – should be country-specific	

[1] Characterisation factors including climate-carbon feedbacks are assumed to be consistent with Fazio et al. (2018)

[2] For nitrous oxide, tier 1 emission factors are an additional fallback option.

[3] Time period requirements for cradle to farm gate data aren't specified, but slaughterhouse data represent an average of three years, so the same is assumed for primary production.

4.1.6 Review of Australian frameworks, methods and tools

In this section we have adopted the GRSB format (McConkey et al. 2019) to review three tools developed for use estimating GHG emissions in Australian contexts. These tools are the Sheep & Beef GHG Accounting Framework (SB-GAF), the ERF Cattle Herd Management Method, and FarmGAS ST (scenario tool). An earlier version of SB-GAF had a sister tool for beef feedlots (F-GAF) that is referred to in this document but not formally reviewed here as the features are generally equivalent. As interest in measuring, modelling and mitigating GHG emissions from the beef sector grows, more tools designed for Australian contexts are likely to become available. For example, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) is developing 'LOOC -C', which is a software tool designed to allow land managers to identify and evaluate their options for participating in ERF projects relating to vegetation methods (CSIRO 2019). However, it is unlikely this tool would provide a similar output to those reviewed here, which principally determine emissions directly related to livestock, though some other emission sources may also be included. To conform with UNFCCC guidelines (Section 4.1.2), all tools should apply livestock emission estimation methods described in the NIR (i.e. tier 2 or 3 methods). For this reason, the NIR methods are first briefly reviewed.

NIR Methods for Emissions from Pasture-fed Beef Cattle

Methods for determining emissions from beef cattle on pasture are described in the Australian NIR, Section 4 (Commonwealth of Australia 2019a). There are three emission sources, each with their own set of calculations: methane from enteric fermentation (NIR Section 5.4.2.2), methane from manure (Section 5.4.3.1), and nitrous oxide from manure and urine (Sections 5.4.3.2 and 5.6.5). Enteric methane is a function of dry matter intake (DMI) per head per day, manure methane is a function of dry matter digestibility (DMD) and region, and nitrous oxide emissions are determined by calculating excretions via nitrogen mass balance (which is principally influenced by livestock growth and diet crude protein) then emissions from agricultural soil (Fig. 4). Both the methane and nitrous oxide emissions are converted to CO_2-e units using IPCC conversion factors (currently AR4). This methodology is tier 2, country-specific, because it uses country- and region-specific models and parameter values.

Sheep & Beef GHG Accounting Framework (SB-GAF)

B-GAF (Eckard & Doran-Browne 2018) was a spreadsheet tool that calculated scope 1 emissions arising from enteric fermentation, manure management, agricultural soils, savannah burning, liming and urea application (Table 9). It included scope 2 emissions arising from energy use. It was revised by Integrity Ag & Environment as SB-GAF to partially cover scope 3 emissions and sequestration by on-farm tree plantings (P.PSH.1252). The simple interface mirrors the NIR activity data for beef cattle, which requires inputs per season. Conceptually, SB-GAF functions as a carbon accounting tool and now reports emissions on an emissions intensity basis. While the tool is straight forward, the simple interface is restrictive in that the livestock activity data must be provided on a seasonal basis and requires inputs not regularly assessed by producers, such as seasonal ADG: this temporal resolution is incongruous with most farm data, making the tool incongruous with independent auditing. The number of livestock categories are also restrictive, requiring extensive data averaging where more complex farms are modelled with large numbers of cattle moving in and out of the farm. The tool is strictly user driven from accounting data, and does not apply any herd modelling techniques to interpret input data or check inputs against biological norms. Nevertheless, the tool is effective at applying the NIR calculations in a way that is directly comparable with the national accounts.

ERF Cattle Herd Management Method

Like B-GAF, the ERF Cattle Herd Management Method is a spreadsheet tool (Table 10). The objective of the tool is model changes in scope 1 methane and nitrous oxide emissions from livestock in response to herd efficiency gains. It therefore omits other scope 1, as well as scope 2 and 3 emission sources. The model is based on a herd inventory for reference years (against which changes in emissions will be determined) and a reporting year. Like B-GAF, the tool requires input data including of head number and live weight, but determines livestock numbers and live weight gain based on auditable input data such as the date and number of animals moved on and off the farm. The calculator separates livestock into a 'resident' herd (which remains on the farm for the full 12 month period) and a 'transient' herd which includes all cattle moving on or off the farm in a given 12 month period. The tool includes some simplifications, such as an estimated branding weight and

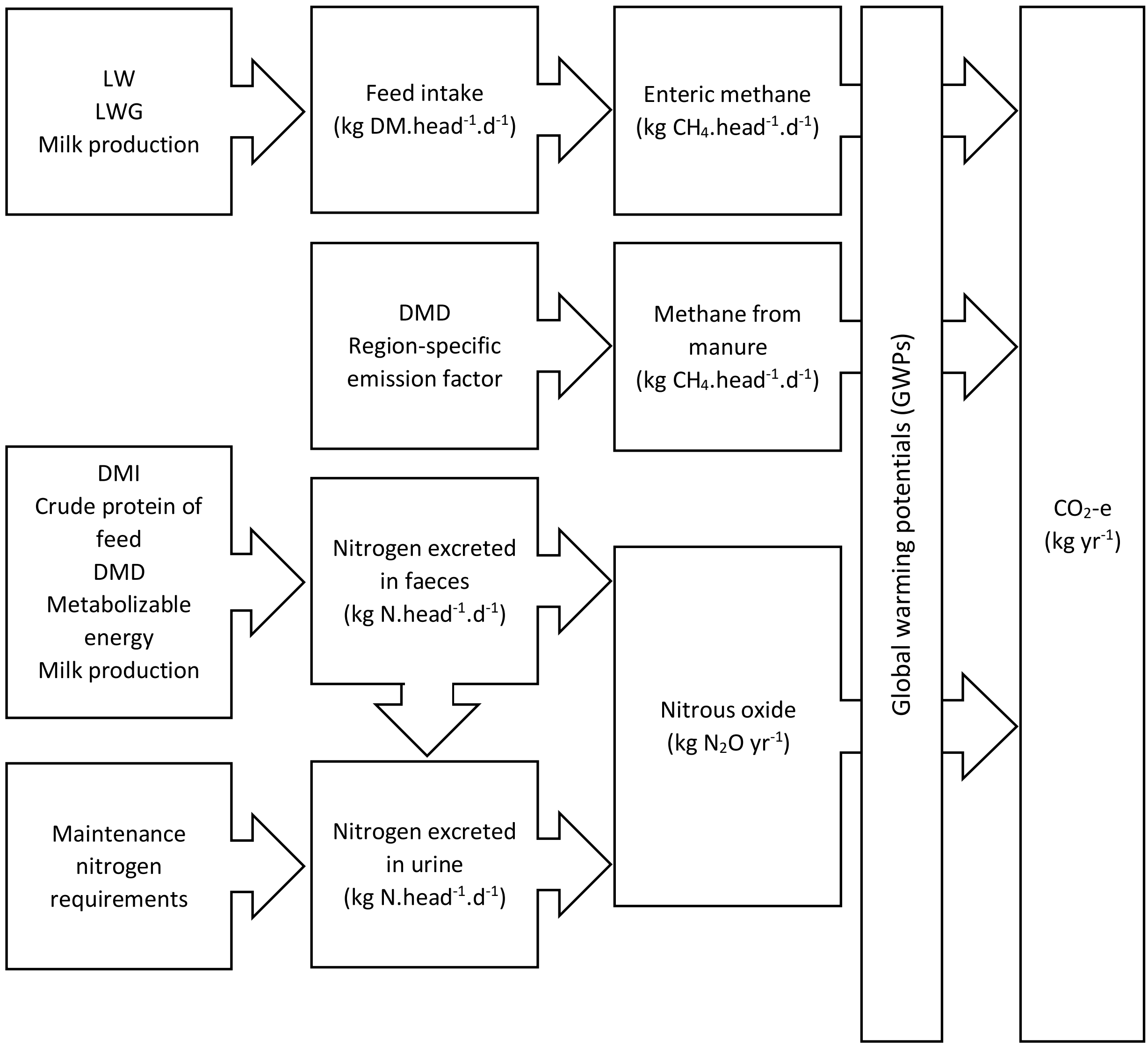
Table 8 – Review of the emission scope of tools for carbon assessment

Calculator	Target countries	Output	Scope 2 emissions included?	Scope 3 emissions included?	Sequestration included?	Consistent with CF? [1]
Bord Bia *Carbon Footprint Model*	Ireland	Emission intensity	Not reported separately	Not reported separately	No	No
OverseerFM	New Zealand	Mass CO_2-e, emission intensity	Yes	Partly [1]	No	No
Cool Farm Tool	Global	Mass CO_2-e, emission intensity	Yes	Partly [1]	Yes	No
Global Livestock Assessment Model (*GLEAM*)	Global	Mass CO_2-e, emissions intensity	Yes	Yes	No	Yes
Integrated Farm System Management (*IFSM*) tool	USA	Emission intensity	Yes	Partly [1]	NA	No
FarmGAS tool	Australia	Mass CO_2-e	No	No	Yes	No
Beef GHG Accounting Framework (*B-GAF*)	Australia	Mass CO_2-e	Yes	No	No	NA
Sheep & Beef GHG Accounting Framework (*SB-GAF*)	Australia	Mass CO_2-e, emission intensity	Yes	Yes [2]	Partly	No
ERF Cattle Herd Management Method	Australia	Mass CO_2-e	No	No	No	NA

[1] Upstream emissions such as those from agrichemical production included, but not those from traded livestock. Consequently, these models will be comprehensive only if a stable, closed herd is modelled.

[2] The scope 3 emissions considered includes the most important sources but is not exhaustive.

Figure 4 – Schematic relationship between data inputs and emission calculations for beef cattle on pasture using National Inventory Report methods (Commonwealth of Australia 2019a). Abbreviations are provided in-full in the text.



age for young calves, and does not explicitly account for mortalities. As with the B-GAF tool, the herd management calculator is strictly user driven from accounting data, and does not apply any herd modelling techniques to interpret input data or check inputs against biological norms. However, one major advantage is that the input data are inherently more verifiable, being based on data that are often verifiable, such as sale and purchase numbers, dates and weights. The ERF tool also requires data on supplementary feed. The model output includes tonnes of CO_2-e as well as CO_2-e t LWG^{-1}. The latter should not be considered a CF given the exclusion of all other emission sources, including scope 3 livestock emissions.

FarmGAS ST (scenario tool)

There are many contrasts between the Australian Farm Institute FarmGAS ST tool (Table 11) and the tools reviewed above. The FarmGAS ST tool has an online interface and provides a method for determining gross margins from livestock and cropping costs and returns. The tool tracks the herd inventory (head number, live weight, live weight gain) on a monthly time-step, with feed factors determined using a seasonal time-step, and final calculations returned on a yearly basis. For grazing cattle, the GHG emission calculation outputs include tonnes per year itemised by gas and source (enteric methane, manure and urine) by area, dry sheep equivalent, and cow. The user guidelines (Madden 2014) indicate the tool implements methods consistent with the NIR, however it is unclear these have been updated to match revisions to NIR methods (Commonwealth of Australia 2019a). The NIR revisions include a 2016 update of the method used to estimate methane emissions from enteric fermentation. Close alignment with the NIR methodology also means the omission of scope 3 emission sources, which makes FarmGAS ST best-suited to carbon accounting. Additional capabilities include modelling of carbon sequestration by on-farm trees, which is a feature shared with the *Cool Farm Tool* (Table 8). Other scenarios that can be explored with the tool include some closely aligned to ERF methods, while others relate to technological advances such as inhibition of enteric methane production and improved genetics.

Climate Active carbon neutral certification

Business operations, products and services, events, precincts and buildings can apply for carbon neutral certification through Climate Active (Table 12). Climate Active is a program administered by the federal Department of Industry, Science, Energy and Resources with assistance from registered consultants and independent verifiers. The process requires setting an emissions boundary, quantifying material emissions (including those from scopes 2 and 3), formal project registration and reporting, the purchase of offsets equivalent to emissions, and a public disclosure. The carbon offsets can be purchased from the carbon market or via compliance with a carbon credit scheme, such as the ERF, which is a separate, substantial task (Section 4.1.4).

Table 9 – Characteristics of the Sheep & Beef GHG Accounting Framework (SB-GAF)

Attribute	Description
Developer	Primary Industries Climate Challenge Centre, The University of Melbourne, revised by Integrity Ag & Environment
Format	Spreadsheet
Geographic focus	Australia
Target audience	Farmers, their advisors and researchers
Cost	Free
Current users	Unknown
Indicators/metrics	GHG emissions
GWPs	28 for CH_4, 265 for N_2O
Scope and boundary of system	On-farm scope 1 and 2 emissions, and partial scope 3.
Notable omissions in scope	Does not assess soil sequestration, or sequestration from native vegetation regeneration.
Guidance on or threshold for excluding emissions	None
Limitations to use	Specific to Australian states and territories, and Australian data. Requires seasonal input data, which is incongruous with farm records, making auditing challenging
Primary data input requirements	Farm location, area, operation, energy and fuel use, transport, savannah burning, and on a seasonal basis: numbers on hand, LW, LW gain, pasture characteristics, fertiliser, and calving percentage;
Emission factor sources	Uses the latest NIR methods
Dataset sources for modelling	Uses the latest NIR methods
Emission method tier	Tier 2
Soil carbon approach	Does not include soil carbon emissions or sequestration
Land use change approach (direct and indirect)	Does not include vegetation carbon emissions but includes sequestration from tree planting
Output unit (i.e. functional unit)	Tonnes of CO_2-e/farm and kg CO_2-e/kg LW
Uncertainty assessment	NA
Other comments on quantification approach	This tool can be utilised to provide some specific tasks in a CF. Provided livestock inventories are reconciled with herd outputs, and a closed, stable herd (or flock) is modelled the results could be reported relative to total production and would provide one key element of a CF.

Table 10 – Characteristics of the ERF Cattle Herd Management Method

Attribute	Description
Developer	Australian Department of the Environment and Energy
Format	Spreadsheet
Geographic focus	Australia
Target audience	Project developers seeking carbon credits from the Australian government ERF for undertaking strategies designed to reduce emissions from grazing livestock
Cost	Free
Current users	There are approximately five registered projects
Indicators/metrics	GHG emissions
GWPs	28 for CH_4, 265 for N_2O
Scope and boundary of system	On-farm livestock emissions covered. Designed to compare emissions between a reference period and a project period (i.e. where emission reduction strategies were implemented)
Notable omissions in scope	Omits CH_4 from manure. Purposefully omits scope 2 and 3 emissions, and omits scope 1 emissions.
Guidance on or threshold for excluding emissions	None
Limitations to use	Considers enteric methane and nitrous oxide from manure and urine only. Does not include energy-related scope 3 livestock emissions.
Primary data input requirements	Random sample of LW to identify sample number requirements, LW per class, feeding period by feed type per class, movement dates and associated LW by class
Emission factor sources	Uses the latest NIR methods
Dataset sources for modelling	Uses the latest NIR methods
Emission method tier	Tier 2 (inferred from NIR)
Soil carbon approach	Does not include soil carbon emissions or sequestration
Land use change approach (direct and indirect)	Does not include vegetation carbon emissions or sequestration
Output unit (i.e. functional unit)	Tonnes of CO_2-e/farm, tonnes of CO_2-e/tonnes liveweight gain
Uncertainty assessment	NA
Other comments on quantification approach	Requests random sampling to identify a representative number of LW measurements

Table 11 – Characteristics of FarmGAS ST

Attribute	Description
Developer	Australian Farm Institute
Format	On-line
Geographic focus	Australia
Target audience	Farmers, their advisors and researchers
Cost	Free
Current users	Unknown
Indicators/metrics	GHG emissions, economics
GWPs	21 for CH_4, 310 for N_2O as defaults but these can be modified
Scope and boundary of system	Cradle to gate for farm and enterprise scales
Notable omissions in scope	Omits carbon dioxide and emissions from liming, organic fertiliser, soil carbon sequestration
Guidance on or threshold for excluding emissions	None
Limitations to use	Specific to Australian states and territories, and Australian data. Appears to omit scope 2 emissions from electricity, all scope 3 emissions, scope 1 emissions from on-farm services
Primary data input requirements	Farm location, area, operation, pasture characteristics, numbers on hand each month, weaning and lactation, liveweight, LW gain, feed intake
Emission factor sources	Uses potentially out of date NIR methods
Dataset sources for modelling	Uses potentially out of date NIR methods
Emission method tier	Designed to conform as closely as possible to Tier 2
Soil carbon approach	Does not include soil carbon emissions or sequestration
Land use change approach (direct and indirect)	Includes carbon sequestration by tree lots but not by soil, and does not model changes in land use beyond typical operation activities (livestock, cropping, horticulture)
Output unit (i.e. functional unit)	Tonne of gas per year, t CO_2-e/year, t CO_2-e/ha, t CO_2-e/DSE, t CO_2-e/head, t CO_2-e/kg beef (feedlot only)
Uncertainty assessment	NA. Alternative scenario modelling possible
Other comments on quantification approach	Includes diverse scenarios including tree lots and enteric methane inhibitors, among others.

Table 12 – Characteristics of Climate Active carbon neutral certification

Attribute	Description
Developer	Climate Active
Format	Formal program
Geographic focus	Australia
Target audience	Clients seeking public disclosure of carbon neutral status
Cost	Substantial – includes consultant, verification and certification fees
Current users	Publicly disclosed
Indicators/metrics	GHG emissions
GWPs	Compliant with NIR methods
Scope and boundary of system	Must include scope 1, 2 and 3 emission sources
Notable omissions in scope	None
Guidance on or threshold for excluding emissions	None
Limitations to use	Specific to Australian states and territories
Primary data input requirements	All material inputs. Must be verifiable
Emission factor sources	Must be defensible to pass verification
Dataset sources for modelling	Must be defensible to pass verification
Emission method tier	Must be defensible to pass verification
Soil carbon approach	Program will recognise soil carbon credits obtained externally
Land use change approach (direct and indirect)	Not clear. Vegetation carbon credits may be used as offsets
Output unit (i.e. functional unit)	Tonnes of GHG (t CO_2-e) (organisations) or kg CO_2-e/functional unit (products)
Uncertainty assessment	NA
Other comments on quantification approach	Includes diverse products so there are no methods relating specifically to beef production systems

Frameworks that Report Industry Emissions

To be of applied value, tools developed for Australian contexts should align with domestic strategies pursued by industry to measure, monitor and mitigate GHG emissions from the beef production sector. For context, the two most relevant industry reporting frameworks are described below.

Australian Beef Sustainability Framework

The Australian Beef Sustainability Framework (ABSF) lists six priorities to produce beef in a socially, environmentally and economically responsible manner (ABSF 2019). One of these priorities, ‘Mitigate and manage climate change’ relates directly to sources and sinks for GHG emissions from beef production. This priority is evaluated using five indicators that are reported upon and monitored annually to assess progress:

1. Emission intensity: mass of CO_2-e per mass of LW at the farm gate,
2. Mass of CO_2-e per mass of hot standard carcass weight (HSCW) at the processor,
3. Carbon captured and re-used during processing,
4. Carbon sequestration,
5. Total emissions (CO_2-e) reduced by the industry relative to a 2005 baseline.

These indicators have not been developed as part of the ABSF; instead, they have been based on various reports and studies that are cited by the ABSF. The key features of each are described below.

1. Emissions intensity: The first indicator reports the emission intensity of the beef slaughter herd, assessed using a life-cycle-assessment (CF) method with a cradle-to-farm gate system boundary. This study developed a purpose-built livestock inventory for the Australian beef slaughter herd, reconciling livestock performance data and herd outputs. It uses GHG estimation methods for livestock, soils and vegetation that are generally not inconsistent with the NIR. Activity data for the livestock herd and all other inputs were developed independent of the NIR. A full description of the methods used is available from the cited publication (Wiedemann, Henry, McGahan, Grant, Murphy, et al. 2015).
2. CO_2-e per HSCW: This indicator is the average emission intensity of red meat processing including rendering at approximately a dozen facilities. It includes scope 1 and 2 emission sources but excludes pre-processing (scope 3) emissions (Ridoutt et al. 2015).
3. Carbon captured and re-used during processing: This indicator reflects potential to reduce the CF of red meat processing by using biogas from wastewater treatment as an energy source. It is based on energy use at 14 facilities. The ABSF interpreted this parameter in terms of carbon, however the original report expressed the parameter in energy (MJ.t $HSCW^{-1}$) (Ridoutt et al. 2015). The interpretations directly align only if carbon per unit of energy is equivalent for captured biogas and other energy sources used.
4. Carbon sequestration: In the absence of a widely agreed methodology, the ABSF did not report against this indicator in 2019, but expected suitable measures to come from the MLA CN30 initiative (see below).
5. Total emissions from the red meat industry. This reported number was derived from a CSIRO study (Mayberry et al. 2019; Mayberry et al. 2018) that utilised data, methods and results from the NIR, and reported these for the beef industry and is therefore not inconsistent with the NIR for comparable emission sources. Attempts were made to include scope 1, 2 and 3 emissions. The study did not develop or interrogate the activity data used to determine livestock emissions and therefore did not include the same activity data as the study used to report emissions intensity.

Meat & Livestock Australia CN30 Program

Meat & Livestock Australia launched an ambitious program to achieve carbon neutrality in the red meat production sector by 2030 (i.e. the CN30 program) (MLA 2017). Pathways to achieve this target include (Mayberry et al. 2018):

1. Land-use change (reduced deforestation, savanna burning management, reforestation),
2. Technologies to reduce enteric methane production,
3. Increases in efficiency via management, in combination with reduced animal numbers.

The baseline report commissioned to underpin this program is also used to report total emissions (item 5 above) under the ABSF and has therefore been described above in general. Key emission sources covered by this report included:

1. Energy: farms, feedlots and processing,
2. Agriculture: enteric fermentation, manure management, soils, stubble burning, lime and urea use,
3. Land-use, land-use change and forestry: emissions from, and land conversions to, forest, crop and grasslands.
4. Waste-water treatment.

4.1.7 Review of methods in the carbon assessment literature

A selection of peer-reviewed manuscripts reporting carbon assessments for Australian beef production systems were reviewed to identify the assessment tools used, emission scope and whether land use and land use change carbon emissions and sequestration were included in the methodology (Table 13). The rationale was that the peer-reviewed literature would show (1) the most advanced tools and methods for CF, and (2) dual interest in emission sources and sinks in applied contexts, as shown by national programs to monitor, manage and mitigate GHG emissions (Section 4.1.6).

The reviewed studies showed greater inclusion of scope 2 and 3 emissions than tools (Table 7). The inclusion of more emission sources in peer-reviewed studies may reflect the use of sophisticated LCA modelling software and/or more intensive accounting practices in the research community and the link of this software to databases capable of parameterising off-farm processes (e.g. electricity and agrichemical production): many of the manuscripts examined cited the use of LCA software or their associated databases (Table 13).

A small number of the peer-reviewed studies reporting an emission intensity also calculated the rate of on-farm carbon sequestration by trees or soils. The sequestration rates were calculated independently of the emission intensity using FullCAM or data from the peer-reviewed literature. From this it is inferred that industry interest in a broader spectrum of emission and sequestration sources on-farm (Section 4.1.6) is reflected in applied research.

Most emission intensities for Australian beef production were in the range 10 – 15 kg CO_2-e kg LW^{-1}. However, values for feedlot-finished beef were ~10 kg CO_2-e kg LW^{-1} or lower (Table 13). These contrasts present important methodological challenges for carbon assessment across the whole beef production system. The production system will always involve a grass-fed breeding herd, but feedlot finishing has become increasingly important in recent decades to meet consumer preferences and to enable finishing of cattle when grass and forage supply is limited by drought (Wiedemann et al. 2017). Feedlot finishing is particularly important as a strategy to reduce the CF of beef production systems. The emission intensity is lower from this intensive system due to lower lifetime emissions, which are a response to cattle attaining sale weights earlier via high feed conversion rates (Wiedemann et al. 2017). Feedlots are therefore an important component of beef production in Australia for economic and environmental reasons, but their operations are beyond the boundary of a typical cradle-to-farm gate CF assessment. Thus, like on-farm carbon sequestration, a capacity to measure and model emissions from feedlot operations is important for scenario exploration, and for determining GHG emissions across the whole of beef primary production.

Table 13 – Emission sources used to determine emissions from Australian beef production systems in the peer-reviewed literature

Production system/s; region	Terminal boundary	Output	Tools used	Source of livestock data and other input data	Scope 2 emissions included?	Scope 3 emissions from purchases included?	Scope 3 emissions from traded livestock included?	Emissions and sequestration from soil and vegetation included?	Cradle to gate emission intensity (kg CO_2-e kg LW^{-1})	Reference
Grass-finished beef; South-eastern and central Qld	Farm gate	Emission intensity	SimaPro, B-GAF, FarmGAS, FullCAM, published data	Farm survey	Yes	Yes	Yes	No	12.6 – 24.9	Eady et al. (2011)
Grass- and feedlot-finished beef; diverse sites, NSW	Farm gate	Emission intensity	LCI databases, NIR equations	Literature sources – farm gross margins	Yes	Yes	Not stated	No	11.1 – 14.0	Ridoutt et al. (2011)
Grass- and feedlot-finished beef; National	Farm gate	Emission intensity	SimaPro, NIR equations, LCI databases	ABS, ABARES as inputs to custom national livestock model	Yes	Yes	Yes	Separately assessed	13.8	Wiedemann et al. (2019)
Grass-finished beef; eastern Qld and NSW	Farm gate	Emission intensity	SimaPro, NIR equations	Farm survey	Yes	Yes	NA	Separately assessed	11.6 – 13.6	Wiedemann et al. (2015)
Grass- and feedlot-finished beef; Qld and NSW	USA retail	Emission intensity	SimaPro, NIR equations	Farm survey	Yes	Yes	Yes	Yes	NA [2]	Wiedemann et al. (2015)
Grass-fed beef; north Qld	Farm gate	Mass CO_2-e	FarmGAS	Farm survey	Yes	No	NA	Yes	NA	Bray et al. (2014)
Beef; central Qld	Farm gate	Emissions intensity, mass CO_2-e	B-GAF, published data	Farm survey	No	No	NA	No	16.0	Harrison et al. (2016)
Beef and sheep enterprise; NSW southern highlands	Farm gate	Mass CO_2-e	GrassGro, FullCAM, NIR equations	Farm survey	Yes	Yes	NA	Yes, trees	NA	Doran-Browne et al. (2017)
Feedlot finishing [2]	Farm gate and finish	Emission intensity	SimaPro, NIR equations	Farm survey	Yes	Yes	Yes	Separately assessed	10.3 – 11.6	Wiedemann et al. (2017)

[1] Not a liveweight-based functional unit. [2] Focus of this study was feedlot gate: cradle to gate emissions are reported here.

4.2 Preferred carbon footprint methods

Operation carbon footprint

The operation carbon footprint is effectively a business-based carbon assessment framework, which comprehensively assesses all GHG emissions and sequestration sources within the operational boundary of the business, and includes assessment of purchased inputs to the farm, to allow the full carbon footprint of production to be assessed.

A recommended framework for CF assessment in Australian beef supply chains is outlined below (Table 14). These recommendations are consistent with the international standards and industry guidelines. While this standard approach is currently time consuming because of the required detail, a series of simplifications were identified. Some of these simplifications have been achieved through technological advances and availability of new data. Others have been identified through the piloting process. The three main ways to simplify the requirements were:

1. The use of background inventory data to estimate scope 2 and 3 emissions from sources such as the production of purchased fertiliser and feed, as well as livestock,
2. Simplified assumptions regarding land use and land use change (LULUC) emissions, but assuming no change in soil carbon stocks (i.e. no change in emissions or sequestration) in the absence of a major change in land use over the period for assessment (i.e. pasture remained pasture, cropland remained cropland), and
3. Simplified inventory collation for LULUC vegetation change assessment by utilising vegetation data layers obtained from satellite imagery. These data layers are available over long periods of time, making them ideally suited to detecting changes in land use (e.g. deforestation, afforestation, reforestation) over the 20-year timespan recommended by the international standard (ISO 2018) (Table 14).

The standard 'operation' CF approach offers compatibility with on-farm carbon accounting and therefore enables a producer to understand gross emissions from their operation. The methods are consistent with international standards for CF, such as the inclusion of both direct and indirect emissions (i.e. Scope 1, 2 and 3) in the product life cycle. Conversely, emission sources that are minor contributors to the CF of beef production systems (e.g. accounting and veterinary services) are omitted (Wiedemann, McGahan, Murphy & Yan 2015; Wiedemann, McGahan, Murphy, Yan, et al. 2015). Importantly, the methods are consistent with IPCC guidelines to use the highest tier methods available. That is, the methods have as their basis operation-specific primary activity data (collected as per Table 14) and use region- or country-specific methods and databases where available. The Australasian LCI database is recommended as a primary LCI database (Life Cycle Strategies 2015), and the European ecoinvent as a secondary database (ecoinvent 2018).

Table 14 – Key framework elements for an operation-based beef carbon footprint

Item	Recommended value, method or source	Reference
Functional unit	One kilogram of beef liveweight	LEAP (2015a)
Global warming potential (GWP) factors	Consistent with NIR (28 for CH_4, 265 for N_2O)	Commonwealth of Australia (2020a)
Calculation methods	Consistent with NIR	Commonwealth of Australia (2020a)
Operation boundary	Cradle to farm gate	LEAP (2015a)
Temporal boundary	Two production cycles	See Appendix 8.1
Emission sources included	Scope 1, 2 and pre-farm scope 3	LEAP (2015a), ISO (2018), WRI/WBCSD (2007)
Primary data requirements	None	NA
Land use and land use change emissions and sequestration	Amortise over 20 years for all land-clearing and planting events within 20 years of the assessment date	ISO (2018)
Separating impacts between farm sub-systems	Avoided where possible, then allocated on a biophysical basis (land area utilised) or economic basis for separating livestock and cropping	ISO (2006a)
Co-production	Not applicable in beef systems up to the farm gate	Wiedemann et al. (2015)
Herd structure	Must include all animals required to produce the product (i.e. cradle-to-farm gate) including breeding, growing and finishing, even if these occur on different farms	

Simplified carbon footprint assessments

One way to expedite the delivery of practical outcomes to industry relating to operation carbon assessments is to perform lower level carbon assessments that equip the farmer to self-assess impacts with expert input, utilising some default input data where the impact of using these data is below materiality thresholds. It is envisaged that this approach would involve farmers entering inventory data and participating in the calculation process using a calculator platform. As part of the data capture process, this could include investigating novel ways to capture data, including utilising the Livestock DataLink portal managed by MLA. These data would be supplied and low-level verification would be done by experts, and the results and implications would be discussed in a workshop context. The advanced delivery of the data would provide facilitators with time to (1) perform preliminary checks in relation to biological norms and atypical values, and (2) suggest appropriate revisions to participants in time for the workshop. Facilitator and participant confidence in the usefulness of provided data will increase the perceived value of workshop activities.

Participants would be required to provide information to enable the determination of their operation carbon account (i.e. an assessment omitting pre-farm emissions). Participants will be presented with the opportunity to provide further information (e.g. chemical and feed inputs and purchased cattle) to enable the determination of their operation CF and product CF. Completion of the pre-workshop data provision task will be simplified by the option of using regional default values for parameters that may be unknown or difficult to assess (e.g. calving date). This approach will allow participants to tailor their workshop preparation in relation to their prior engagement in the topic of carbon assessments.

The workshop would provide facilitators with an opportunity to (1) explain key concepts relating to carbon assessment, and (2) guide participants in the use and integration of available tools for carbon assessment and modelling sequestration. Along with the individual carbon assessments, outputs from the workshop would be (1) an opportunity to compare carbon assessments with fellow workshops participants and with published reports (e.g. regional averages and case studies), and (2) an opportunity to explore on-farm scenarios to reduce emissions and increase carbon sequestration. This idea was successfully trialled over the course of this project (V.SCS.0016).

The disadvantages of a simplified carbon assessment primarily depend on what compromises are made to the requirements of the minimum standards. For example, if participants provide less than two production cycles of data, the likelihood of a result implying atypical GHG impacts increases. There may be a need to make assumptions regarding land use and land use change to account for the deficiencies of current models and limited expert analysis applied to the farm data. Product carbon footprints and relative contributions to the carbon account will cluster around a central tendency by a degree that depends upon reliance on default data. Workshop participants should be made aware that, although the carbon assessments provide a highly valuable first-order approximation of operation emissions, the reliance on self-reported data may make the outputs unsuitable for external reporting unless a clear information trail is provided to support verification. The immediate benefit of a simplified carbon assessment would be information exchange between facilitators and participants, and the long-term benefit would be greater participant engagement in industry issues regarding GHG emissions from beef enterprises and the methods used to report and mitigate these impacts.

To summarise, we have two methods, one that applies the newly defined minimum standards to determine the operation carbon account and operation CF, and a simplified approach that provides a lower level of analysis. The former is most likely to meet the reporting needs of individual enterprises and of industry, whereas the latter would be highly effective at promoting industry engagement with the issue of emissions from beef enterprises. The challenge is to increase the ease with which the minimum standards can be applied in carbon assessments so the contrast in complexity between these two choices is minimised (thereby increasing implementation of a more scientifically robust and independently verifiable approach). One way to meet this challenge is by developing tools and data retrieval systems that (1) ease the information burden on farmers (e.g. by accessing livestock databases and remotely-sensed spatial information), (2) improve the user interface by integrating outputs from herd and land use modelling (e.g. link SB-GAF and FullCAM outputs), and (3) are supported by explicit protocols that promote the consistent implementation of methods and ground-truthing of model inputs. The development of such tools and systems is beyond the scope of the present project.

Comparison with other methods and recommendations

There is a strong consensus between the operation carbon footprint described here and the tools and peer-reviewed research reviewed above. These similarities include definitions of functional unit and system boundary and the use of Tier 2 (i.e. country-specific) methods. However, as an CF assessment method consistent with international standards, the described approaches includes scope 1, 2 and 3 emission sources in the CF, making it more exhaustive than many domestic and international tools (e.g. *OverseerFM*, the *Cool Farm Tool* and *Integrated Farm System Management* tool include scope 3 with the exception of traded livestock). The objective was to design a methodology based to the greatest extent on independently verifiable records to facilitate auditing and maximise the utility of emission intensities reported by industry. The proposed methods are fit for not only examining product system processes on emission intensity, but also sufficiently rigorous for communicating emission intensities to external parties such as other industry stakeholders and the public. Major contrasts between an NIR-consistent approach and the UECBV framework relate to GWPs, method tiers and primary data requirements: the former requires a simple re-calculation but addressing the latter two contrasts would require further consideration.

The recommended methods compare favourably with the findings of the GRSB review (McConkey et al. 2019) of CF standards and tools in beef production systems. For example, although reviewing LCI databases was beyond the scope of the present report, we have recommended an LCI database and relevant literature. This does not address concerns in the GRSB report such as inconsistencies in systems boundaries for scope 3 emissions from inputs, but the consistent use of a limited number of sources eases the tasks of comparing methods and revising reported emission intensities. The GRSB review also called for consistency in methods and reporting: clearly defining key methodological framework elements and modelling techniques addresses this concern. The GRSB review advocated for soil carbon sequestration to be considered in CF tools and calculators (McConkey et al. 2019). This has been addressed in the minimum standards guidance (Section 4.3.1), as has soil carbon emissions, and vegetation carbon emissions and sequestration.

An operation-CF will be most suitable where there is a requirement for an operation baseline assessment, including focus on both emission intensity and total emissions. This also suits assessment of mitigation strategies or the potential value of participating in carbon markets. However, if a first-order carbon assessment is acceptable and the priority is promoting industry engagement in the topic of minimising GHG impacts, then the determination of a CA or CF using a simplified approach with participatory engagement will be most suitable.

4.3 Simplified set of data requirements

4.3.1 Development of the minimum standards

A working group was convened to develop a set of minimum standards for carbon accounting and carbon footprints in sheep and beef farms for the Australian context. The minimum standards are presented in-full in the Appendix and summarised here (Table 15). The rationale was to focus on material items (i.e. exclude items that have a minor impact on a carbon footprint or account), and to foster comparability across research groups performing carbon assessments in Australian red meat production contexts. The standards do not provide detailed methods. Rather, users are directed to other documents to the maximum extent possible, and are expected to refer to the peer-reviewed literature and international standards to address items not covered. It is expected that NIR methods (or those not inconsistent with the NIR) (e.g. emission factors, characterisation factors) are used as a default. A livestock production inventory covering two livestock production cycles was considered a minimum requirement.

With a view to simplifying carbon assessments, the working group identified areas where data and models from third party sources should be considered acceptable, where (in the absence of land use change) it is reasonable to assume no change in carbon sequestration by soils or vegetation, and the potential for satellite imagery and modelling to quantify emissions/sequestration resulting from land use change. These opportunities not only simplify inventory requirements, but also have the potential to expediate the process of determining changes in carbon stocks using a method that is not inconsistent with the NIR.

It is emphasised that the minimum standards are more comprehensive than what is presented here. The document includes additional detail on minimum standards for reporting emissions or sequestration relating to vegetation and soil (e.g. land use change, clearing, planting), and calculations (e.g. allocation and functional unit).

The minimum standards have been freely provided to service providers working on carbon assessments in the Australian red meat industry.

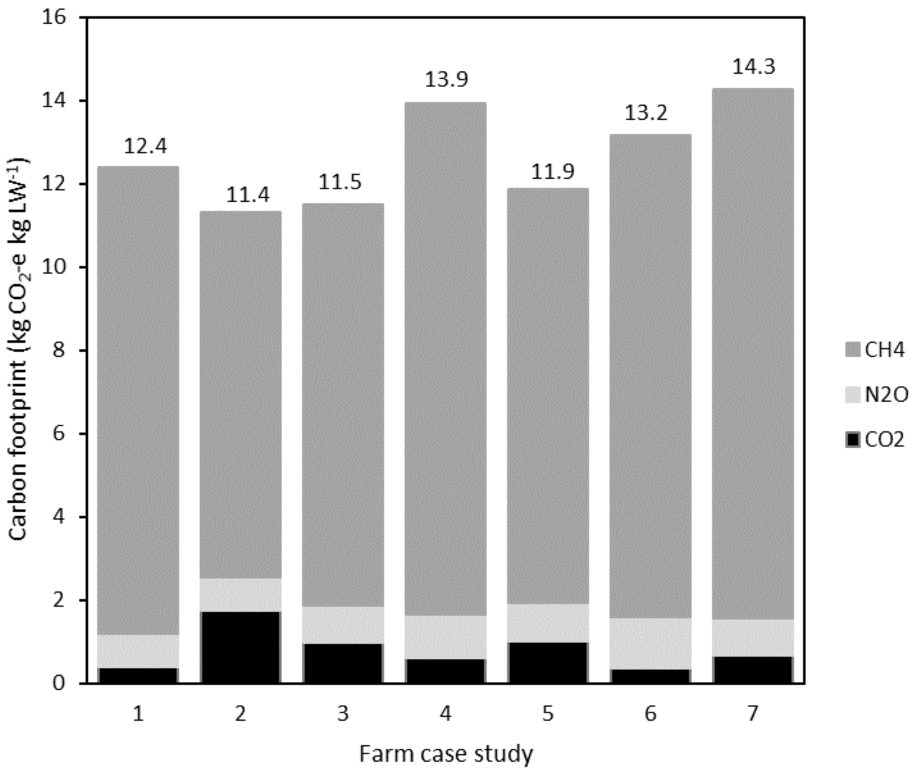
Table 15 – Key framework elements for an operation-based beef carbon footprint

Key elements	Livestock emission sources	Emissions from fertiliser and crops	Emissions from purchases	Emissions from and sequestration in vegetation and soil (land use and land use change)
Processes	Feed intake Enteric methane Manure methane Indirect emissions	Soil and fertiliser-related emissions Indirect emissions Residue emissions	All purchases (after applying a materiality cut-off)	Land use change – vegetation (over the last 20 years) Land use change -soil carbon (over the last 20 years) Managed fire
Activity data	Livestock numbers and head days Livestock weight Livestock growth rates Pregnancy/lactation status Fed intake (feedlots only)	Hectares grown and crop yield Mass of N applied as fertiliser Mass of N applied as purchased manure	Diesel use, petrol use Grid electricity use Fertiliser, livestock, fodder, grain, supplements, etc.	Digital maps (e.g. digital NIR layers, pasture layers) Land use (total area, crop area, pasture area suitable for cropping, remnant forest) Land use change - vegetation: clearing areas and events; woody thickening areas and events; planting areas, species and events Managed fire: areas, timing of burns, land classes burned, biomass burned
Potential third-party activity data	Pasture crude protein Pasture dry matter digestibility Feedlots ration characteristics Residue mass for estimation of burning emissions (i.e. from crops)	Residue mass for estimation of burning emissions (i.e. from crops)	Feed grain inputs Fertilisers	Digital maps

4.4 Case study farm carbon footprints

The CFs of the case study farms ranged from 11.4 kg CO_2-e kg LW^{-1} (case study 2) to 14.3 kg CO_2-e kg LW^{-1} (case study 7) (Figure 5). For all producers, the GHG that made the largest contribution to the CF was methane (77 to 91 % of total emissions) (Figure 5). Emissions of N_2O were consistently in the range 6.3 – 9.4 %, and CO_2 emissions were in the range 2.6 – 15.3 % (Figure 5). The CFs reported here encompass the range observed across the literature for Australian beef production (Section 4.1.7).

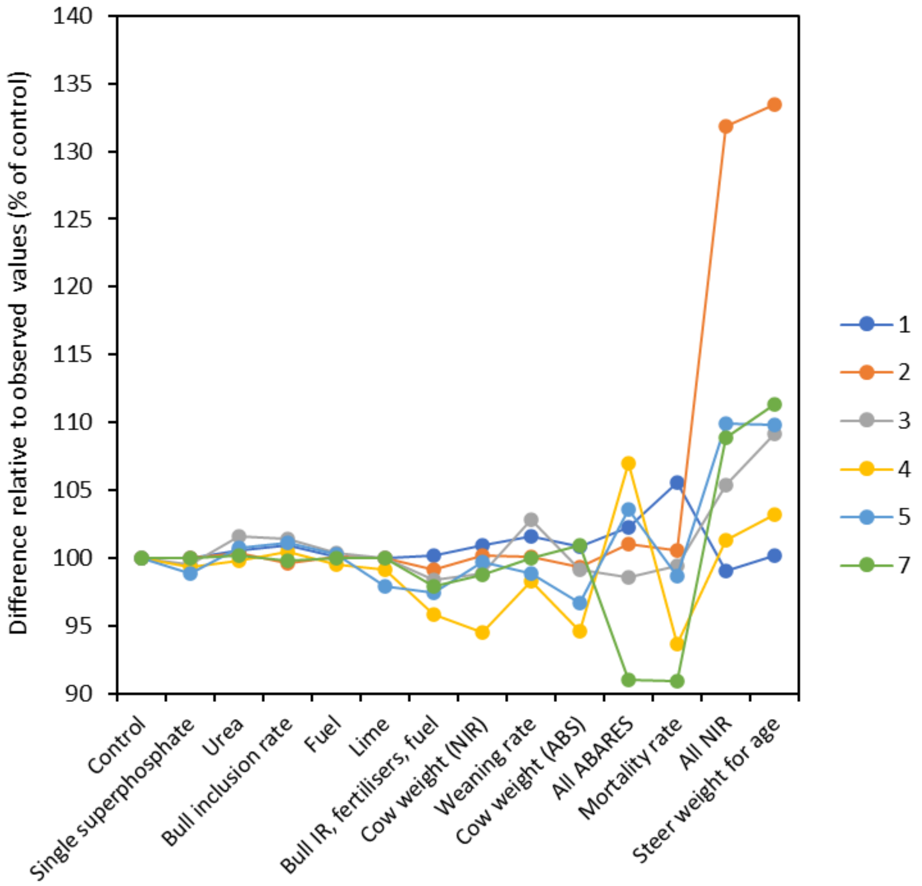
Figure 5. The contribution of greenhouse gases to the carbon footprint of case study



4.5 Analysis of key variables

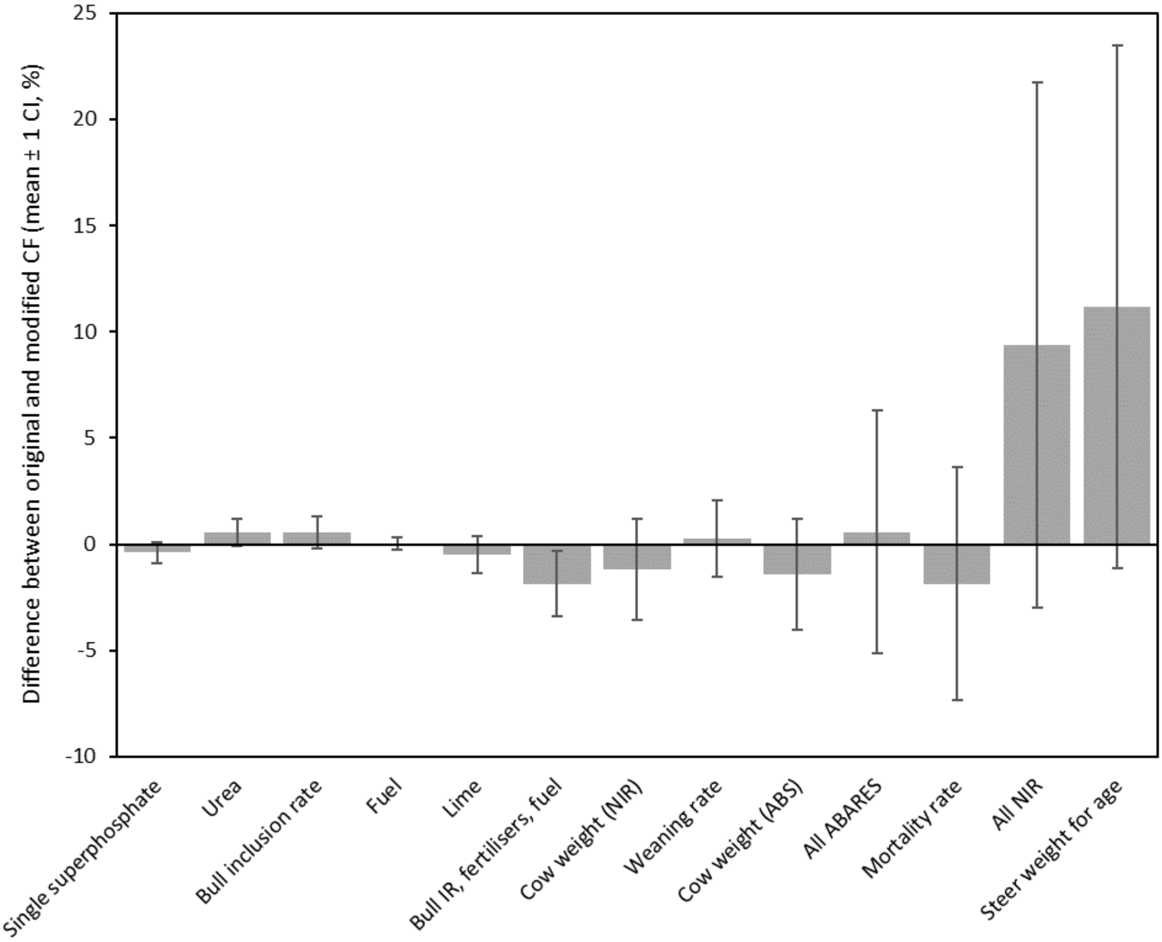
For individual farms, substituting default (regional or state) values produced CFs both lower and higher than those obtained using case study original values (Figure 6). Substituting into the model NIR steer weight for age values produced CFs much greater than the original CFs, especially for case study 2. Steer weight for age had a large positive effect because the substituted values were lower than the original values (Table 6). Substituting mortality rates also increased the CF because the substituted values were often twice as large as the original value (Table 6 – case study 7 being an exception). Conversely, substituting in cow weight (NIR or ABARES) often decreased the apparent CF. This was because the substituted values were up to 25 % lower than the original values for some case study farms (Table 6). Other substitutions showed large changes in CFs both above and below the original CFs (e.g. all ABARES data, all NIR data) (Figure 6). This shows the CF was sensitive to the values of these substituted parameters in farm-specific ways.

Figure 6. The relative difference between carbon footprint assessments determined using original values and substituted regional (or state) default values



Examining the case study farms as a group, the mean difference between the original CF and that resulting from substitutions was often < 3 % but as high as 9.1 and 11.0 % upon substituting all NIR data or NIR steer weight for age data, respectively (Figure 7). The (95 %) confidence interval was very broad for these last two substitutions (a range of 18.8 % for both). The confidence interval was also broad when default values for the mortality rate were substituted (8.7 %), and when all ABARES parameters were substituted as a set (9.4 %). For all other substitutions, the confidence interval was narrow (< 4 %) and often close to or overlapping zero.

Figure 7. The mean change in carbon footprint assessments when substituting regional (or state) default values for original values

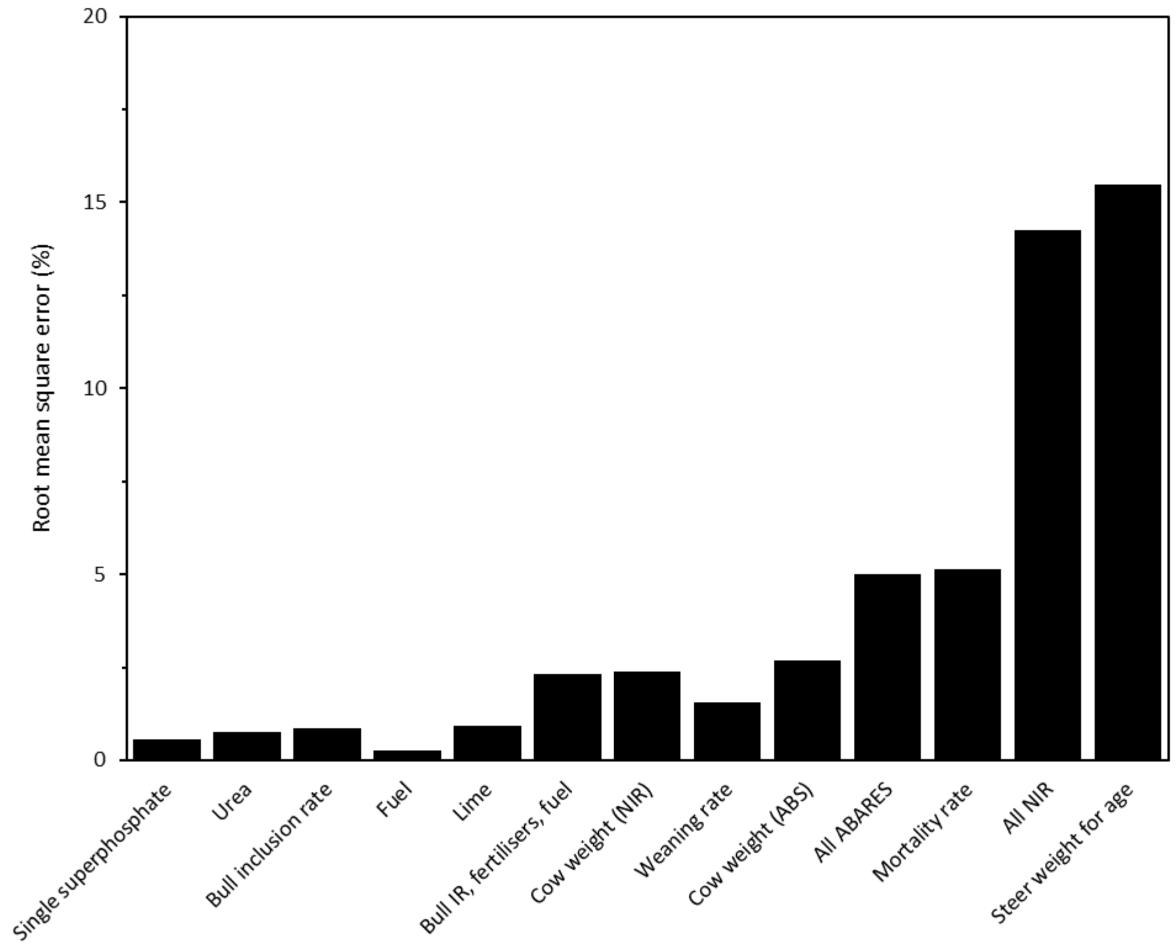


The variation between the individual case studies was often highly skewed (Figure 7), which reduces the relevance of confidence intervals calculated for normal distributions. To address this, the root mean square error (RMSE) was used to examine the net change (expressed a percentage, regardless of whether it was positive or negative) in the CF upon replacing original with default values across all case study farms (Figure 8). The RMSE showed that those parameter substitutions associated with large differences from original values or large confidence intervals (Figure 7) were also associated with large RMSEs (Figure 8). The RMSE results were consistent with the absolute changes in CFs (Figure 7) in that both showed that substituting default regional (or state) values for individual farm services or bull inclusion rate produced small changes (< 2 %) in the CF. Of the purchased inputs, the default superphosphate and lime values produced the largest deviations from the original CF (Figure 8). When all farm services values were substituted as a batch, the RMSE increased to 2.6 % (Figure 8). This increase is less than the sum of individual farm service RMSE values (4.1 %, results not shown), indicating that increases in the CF brought about by some substitutions were cancelled by decreases brought about by others. Similar cancelling effects were observed when the ABARES and NIR data were substituted as sets. For example, upon the substitution, the RMSE was larger when NIR steer weight for age values were substituted than when *all* of the data obtained from the NIR was substituted. This was because relatively unproductive NIR ADG values (which would increase the

CF) were partly compensated by NIR cow weights which were lighter (which would require less feed and therefore emit less methane).

An important caveat to the interpretation of the present results is the statistical representativeness of the case studies used to explore the substitution of default parameters. The number of case studies was small relative to the size of the industry (n = 48,000, MLA 2018), and they were not chosen randomly. The case studies reflect producers who were engaged with the process of CF assessment and a range of contexts that were anticipated to deliver a range in CFs. A more representative set of case studies would have a larger, randomly selected sample size, and the result summary would be weighted to reflect the degree to which the sampled enterprise types reflected the population of beef producers. Despite consistency in key observations (e.g. default values for farm services can be substituted without introducing large errors in CFs), the present results should be interpreted with caution.

Figure 8. The mean change in carbon footprint assessments when substituting regional (or state) default values for producer-supplied values



5. Conclusion

5.1 Key findings

The implications of substituting default values varied with scale – as expected, results for individual farms were more variable than those of the group (Figure 6 and Figure 7). Minor deviations from the original CF are most desirable, but moderate increases in the CF are also acceptable from a reporting perspective because they represent conservative estimates of the CF. However, default value substitutions showed a variety of effects, encompassing both non-conservative and conservative changes to the CF. Of the tested parameters with a RMSE > 4 %, mortality rate and steer age and weight consistently produced conservative CFs. However, for steer age and weight, the variation was unacceptably large. For example, the CF for case study 2 increased by 33 % upon substituting steer weight for age, shifting the CF from the lowest to be approximately equal to the highest amongst the original set of CFs.

At both the individual farm and group scales, the results reported here (summarised in Table 16) are consistent with the idea that some inventory items for beef producing farms are (1) relatively minor (but not immaterial) contributors to the CF and (2) do not vary when comparing individual farms with regional datasets in a way that produces a large (i.e. confidence interval range < 2 % and mean within 2 % of zero at 95 % confidence limits) change in the CF (Table 16). These inventory items include all farm services considered to be potentially substitutable for farmer-reported values (fuel use, etc.). There is high confidence substituting in default values for all farm services because, as a batch (in combination with bull inclusion rate), these changed the CF by ≤ 4 % (at 95 % confidence) (Table 16).

Herd productivity data considered to be potentially substitutable were bull inclusion rate, weaning rate, and cow weight (inferred from ABS or NIR data) (i.e. confidence interval range < 4 % and mean within 5 % of zero at 95 % confidence limits – Table 16). The inventory items that should not be substituted with regional default values were mortality rate and steer weight for age, along with whole-batch substitutions of all ABARES or NIR parameter values (confidence interval range > 4 %). These results are consistent with the preliminary findings for case study farm 6. This particular case study showed that using substituting reported farm services values for state averages decreased emissions from the breeding herd by 1 %. Conversely, substituting herd parameters (bull inclusion rate, replacement heifer/bulls, and average cow weight) decreased emissions by 9 %.

The NIR data on ADG/weight for age was problematic for two reasons. First, errors were introduced during the process of updating the report – the same numbers appear in the reports for 2013 and 2018 but under different class headings. Here we have assumed the earlier values were correct. Second, some of the values are implausible. For example, the annual average ADG for some classes expected to be growing was zero (e.g. South Australian steers and bulls > 1 year, Pilbara steers < 1 year). The sub-par quality of this dataset offers an explanation as to why substituting steer weight for age lead to large deviations from the original CFs (Figure 6, Figure 7), and highlights the need for high quality data in reference documents such as the annual NIRs.

The mortality rate was expected to be an important determinant of the herd CF because it directly impacts production efficiency. The regional default mortality rate was generally higher than the rate reported by the case study farms (Table 6). Accordingly, substituting regional defaults for original mortality rates generally increased the CF (Figure 6, Figure 7). The mortality rate at all scales, from farm to region or state, is likely to be low (e.g. generally < 3 % across the case study regions according to the ABARES data). At such small rates, small absolute changes in mortalities may translate into large deviations from regional trends, making this parameter less suitable for substitutions.

Table 16. Summary of effect of substituting default values for original values across all case study farms

Parameter group	Description	Change upon substitution (%)*			
		-1 confidence interval	Mean	+1 confidence interval	Confidence interval range
Herd production	Bull inclusion rate	-0.2	0.6	1.3	1.5
	Cow weight (NIR)	-3.6	-1.2	1.2	4.8
	Weaning rate	-1.5	0.3	2.0	3.6
	Cow weight (ABS)	-4.2	-1.5	1.2	5.4
	Mortality rate	-6.1	-1.1	3.9	10.0
	Steer weight for age	-1.2	11.2	23.5	24.6
Farm services	Urea	-0.1	0.5	1.2	1.3
	Fuel	-0.3	0.0	0.3	0.6
	Single superphosphate	-0.9	-0.4	0.1	1.0
	Lime	-1.4	-0.5	0.4	1.8
Combinations	Bull inclusion rate, fertilisers, fuel	-3.5	-1.9	-0.3	3.3
	All ABARES	-5.8	1.4	8.6	14.3
	All NIR	-3.0	9.3	21.7	24.8

* Data from Figure 7

In Section 4.2, two types of CF were identified as preferable, depending on the context – an operation CF (suitable in business contexts) and a simplified CF (suited to engaging producers in the concepts of carbon assessments and providing a first-order estimate of impacts). The findings of this research are most relevant to a simplified CF because of its reduced demands for primary data. Simplified CFs are also more likely to be amalgamated than operation CFs, which has the benefit of reducing the effect of outliers potentially introduced if substituted values are not close to original values (e.g. case study 7 in Figure 6). Of the framework elements identified by the minimum standards (Section 4.3 and Appendix), the results suggest that activity data relating to farm services (i.e. those listed in Table 5) may be substituted without produced large (> 2 %) changes in the CF. The results also suggest that some herd parameters may be confidently substituted. Of these, bull inclusion rate can be more confidently substituted than cow weight because (1) the effect on the CF was smaller and less variable (Figure 7), and (2) cows make up a large proportion of a herd (approximately 30 – 50 % by head, more by emissions), making CFs inherently sensitive to cow weight. For this reason, we recommend using regional default values for some parameters, and setting quality control thresholds for others, including cow weight (Table 17).

Table 17. Parameter-specific recommendations on the use of regional default values to simplify beef carbon footprint assessments

Parameters that can be confidently substituted with regional default values	Parameters that should be subject to quality control thresholds
Diesel, petrol, electricity (farm services)	Mortality
Bull inclusion rate	Young cattle weight for age
	Cow weight
	Weaning rate

5.2 Benefits to industry

The findings of this project promote producer engagement with the concepts of carbon assessment by making the process of determining a CF more practical and efficient.

The minimum standards developed under this project are important for encouraging a systematic approach to the CF process. These standards set the framework upon which industry efforts to achieve carbon neutrality will be assessed. A direct benefit of the minimum standards included their adoption to inform MLA case studies of 50 producers (V.SCS.0016). These workshops identified revisions to the B-GAF tool that were subsequently implemented under a follow-up project (P.PSH.1252). As shown here (Section 4.1.6), the subsequent SB-GAF tool allows both business accounting (scopes 1 and 2) and an approximate carbon footprint (including scope 3), which is a first for Australian red meat production systems. SB-GAF is now being utilised in a series of Landcare workshops across Australia and more broadly. As the present project demonstrates, further research investment is likely to identify further opportunities to improve the ability to perform carbon assessments in beef production systems, and these improvements can be immediately extended to producers.

The present research shows the process of providing inventory data to a simplified CF calculator can be improved by providing regional default values for farm services (diesel, petrol, superphosphate and lime) and bull inclusion rate. Conversely, CF calculators would benefit by setting quality control thresholds on user input relating to mortality rate, young cattle weight for age, cow weight and weaning rate.

6. Future research and recommendations

- Achieving the CN30 target requires producer engagement with the concepts of carbon assessment. The findings of this project promote this engagement by making the process of determining a CF more practical and efficient. The minimum standards developed under this project are important for encouraging a systematic approach to the CF process. Importantly, the minimum standards stipulate that all emission scopes (1, 2 and 3) be accounted for. This aligns beef industry carbon assessment with international standards, as well as the system boundary of carbon neutral certification. The latter is conceptually important if achievements against the CN30 target are to be met.
- The SB-GAF calculator (developed from S-GAF and B-GAF under project P.PSH.1252) uses a small number of default values relating to trade cattle. The present research shows the process of providing inventory data to a simplified CF calculator such as SB-GAF can be improved by providing regional default values for the bull inclusion rate and many farm inputs (especially fuel and fertiliser). Default values could be used to pre-populate the activity data once region is provided.
- Conversely, the present research stresses the importance of herd productivity parameter values as determinants of a farm CF. CF calculators would benefit by setting quality control thresholds on user input relating to mortality rate, cow weight, and young cattle weight for age.
- The use of default parameters to simplify CF assessments increases the need for high quality reference datasets. Datasets such as the ABARES specialist beef producers, ABS slaughter weights, and NIR liveweights, ADG/weight for age, DMI, dry matter intake crude protein, should be critically reviewed and recommendations made for their improvement, either by expanding the range of parameters surveyed or by reviewing and revising assumptions.
- The above findings should be considered in future industry investments in carbon assessment tools. Simplifications such as those identified here are important for facilitating the upscaling of CF assessments across the Australian beef industry. Simplification is a means of allowing broad engagement with carbon assessment. Simplification is also appropriate as the productivity-weighted sample size increases to become better represented by regional default data – examples include large supply chains and large groups of producers.
- The minimum standards developed as part of this research is intended to be a working document. A working group should be convened in approximately 18 months' time (end of 2022) to review the relevancy of the standards and revise them as appropriate. This would set a revision interval of approximately three years.
- Opportunities for further research include addressing important knowledge gaps, such as the role of soil carbon under pasture and native vegetation regeneration in sequestering carbon, and documenting the management practices of highly productive, low carbon producers so these findings can be extended across the industry.
- Opportunities for further research also include working with large supply chains to determine their carbon footprint, working with industry to identify baseline emissions and emission hotspots, and value-adding to other research and development investments by obtaining data required for carbon assessments from their experimental treatments.

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8. Appendix

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

Version 1.0, 24-10-2019.

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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 14040/44 (ISO 2006a; ISO 2006b), ISO 14067(ISO 2018) and the LEAP large (LEAP 2015a) and small (LEAP 2015b) 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.

Livestock Emission Sources

National Inventory report (NIR) (Commonwealth of Australia 2020a) methods must be applied for:

- Feed intake,
- Enteric methane,
- Manure emissions,
- Indirect emissions.

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:

- Livestock numbers and head days,
- Livestock weight,
- Livestock growth rates,
- Pregnancy/lactation status,
- 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:

- Pasture crude protein,
- Pasture dry matter digestibility,
- Manure ash content,
- Feedlot ration characteristics,
- 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.

Emissions from Fertiliser and Crops

NIR methods must be applied for:

- Soil and fertiliser related emissions,
- Indirect emissions,
- 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:

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

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

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

Emissions from Purchases

A CA must include on-farm diesel use and petrol use as scope 1 emissions. Emission factors from the NGERS(Commonwealth of Australia 2017) must be applied.

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.

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.

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:

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

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

- Feed grain inputs – may be accessed from the AusLCI (ALCAS 2017) database, other reputable databases using Australian emission estimation methods for Australian crops, or country specific published research,
- Fertilisers – may be accessed from the AusLCI database.

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 18 – Table 24. An example of how these emission and sequestration sources and sinks would be compiled in a CA is provided in Table 25.

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.

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:

- Existing maps (NIR layers, pasture layers). Provide these, then use maps to guide additional information capture.
- Farm questionnaire including:
    - Land Use:
    - Total land area used
    - Total crop land area
    - Total pasture land area suitable for cropping (arable land)
    - Total land area classified as remnant forest
    - Land Use Change – vegetation:
    - Total land area cleared in the previous 20 years.
    - Total land area subject to regrowth (i.e. after a clearing event) and when did regrowth commence?
    - Total land area subject to woody thickening and when did woody thickening commence?
    - Area of trees planted, species and year of planting.
    - Land Use Change – soil carbon
    - Total pasture area converted from cropping to permanent pasture (or vice versa) in the previous 20 years.
    - Other soil carbon related questions?
    - Are soil tests available that provide evidence of soil carbon levels and change over time? If so, please provide.
    - Managed Fire
    - Area burned as part of routine management?
    - At what time of year were managed fires lit?
    - What land classes were burned?
    - What is the estimated biomass (tonnes dry matter) that were burned?

Other Issues

Global Warming Potentials

Current NIR report values shall be applied. Methane = 28, nitrous oxide = 265.

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:

- 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.
- 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.
- Allocation between greasy wool and live weight. Proposed method is the ‘protein mass’ allocation method (Wiedemann, Ledgard, Henry, Yan, Mao, et al. 2015) as a simplified biophysical approach.

Table 18 – 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	No	Short term – aligned with assessment	Previous 20 years	Minimum standard: spatially enabled approach to report emission data from NIR	Yes

matter (DOM) (sparse woody vegetation <20% canopy cover)				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. 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 19 – 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 18)	Yes
Wildfire	Yes	NA	NA	As above (Table 18)	No

Table 20 – 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 21 – 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 22 – 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 18)	Yes
Change in live biomass (sparse woody vegetation <20% canopy cover)	Yes	Short term – aligned with assessment	Previous 20 years	As above (Table 18)	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 18)	Yes
Change in grass dead organic matter (DOM)	No	Short term – aligned with assessment	Previous 20 years	As above (Table 18)	Yes
Change in grass live biomass	No	Short term – aligned with assessment	Short term – aligned with assessment	As above (Table 18)	Yes

Table 23 – 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 24 – 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

Table 25 – 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*: 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 †	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					

* For consistency, other agricultural inputs need to be modelled using equivalent methods and boundaries.

† Dead organic matter