Final report

Pathways to carbon neutrality for Australian feedlots

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Glossary

ACCUs	Australian Carbon Credit Units (ACCUs) are regulated financial products (carbon credits) under the Carbon Credits (Carbon Farming Initiative) Act 2011 administered by the Clean Energy Regulator through the Emissions Reduction Fund (ERF).
Carbon accounting	The process used to quantify greenhouse gas (GHG) emissions from an enterprise.
Carbon footprint	The process of quantifying GHG emissions emitted directly or indirectly by an individual, company or product (i.e. the sum of scope 1, 2 and 3 emissions). A carbon footprint is more commonly used for products (i.e. beef) than enterprises, but it can be applied at either scale. Several standards exist to define a carbon footprint, such as ISO 14067.
Carbon neutrality	The sum of GHG emissions is completely offset by equivalent carbon sequestration. This may be achieved within an enterprise or by purchasing carbon credits.
Carbon sequestration	The process whereby carbon dioxide is removed from the atmosphere and stored in carbon sinks such as soils and vegetation.
Carbon Sink	A reservoir that absorbs carbon dioxide from the atmosphere. Natural carbon sinks include plants, soils and the ocean.
Carbon stocks	A carbon stock refers to the quantity of carbon that has been sequestered from the atmosphere and is stored in a carbon sink.
CERs	Certified Emission Reduction (CERs) carbon credits issued under the Clean Development Mechanism (CDM)
CO_2-e	Carbon dioxide equivalent. 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}).
DMI	Dry matter intake. The amount of moisture free feed an animal consumes.
Emission intensity	Emissions relative to output (i.e. CO_2-e per kg of LW sold or CO_2-e per kg of LWG). Emission intensity values allow for comparison and benchmarking between farms of different sizes. They are the standard unit for a product carbon footprint.
Emission Reduction Fund (ERF)	The Emissions Reduction Fund (ERF) is a voluntary scheme that aims to provide incentives for a range of organisations and individuals to adopt new practices and technologies to reduce their emissions. They provide multiple methodologies to generate ACCUs.
Enteric methane	Enteric methane is produced through enteric fermentation where plant material is broken down in the rumen. Enteric methane is the by-product of this process and is expelled by the animal through belching.
FullCAM	The Full Carbon Accounting Model is a tool used for modelling GHG emissions from Australia's land sector.
Global warming potential (GWP)	GWP is a measure of cumulative radiative forcing, which aims to quantify the long-term contribution of a gas to global warming. Each GHG has a specific GWP value and this is relative to a specified time period (typically 100 years, but values are also available for 20

	year and 500-year time horizons). For the 100-year time horizon, this is abbreviated as GWP_{100}.
Gold Standard	Gold Standard is a voluntary international GHG standard that provides methodologies to ensure projects that reduced carbon emissions feature the highest level of integrity in line with the Paris Climate Agreement and the Sustainable Development Goals.
Greenhouse gases (GHGs)	Gases that absorb and emit radiant energy. The main GHGs associated with agriculture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).
Livestock inventory	All information relating to livestock such as births, deaths, sales, purchases, weights and weight gain. Typically reported based on a financial or calendar year.
LWG (Live weight gain)	The weight gain per day for an animal between two points in time (i.e. while in the feedlot).
Net emissions	Total emissions minus carbon sequestration.
National GHG Inventory (NGGI)	The National Greenhouse Gas Inventory accounts for and estimates Australia's GHG emissions.
National Inventory Report (NIR)	The annual report released by the Australian Government with results from the NGGI and the methods used to determine these emissions.
Purchased inputs	Purchased products for the business such as fertilisers, herbicides, pesticides, feed, fuel, livestock and electricity.
Radiative forcing	The difference between incoming solar radiation and outgoing infrared radiation.
Scope 1 emissions	Direct GHG emissions occur from sources that are owned or controlled by a company.
Scope 2 emissions	GHG emissions from the generation of purchased electricity consumed by a company
Scope 3 emissions	GHG emissions that are the consequence of the activities of the company but occur from sources not owned or controlled by the company. Some examples of Scope 3 activities are emissions from purchased cattle or grain, and use of services. These emissions can relate to the supply chain prior to the business (i.e. purchased cattle) or after the business in the supply chain (i.e. meat processing).
Soil organic carbon (SOC)	The carbon component of organic matter in the soil.
Soil organic matter (SOM)	The living and dead organic materials, other than living plant roots, found in the soil.
VCUs	Verified Carbon Units (VCUs) are carbon credits issued by the Verified Carbon Standard
Verified Carbon Standard (VCS)	Verified Carbon Standard (VCS) is a voluntary international GHG standard that provides methodologies to ensure projects that reduced carbon emissions follow a technically sound emission reduction quantification methodology specific to that project type.

VERs	Verified Emissions Reductions (VERs) are carbon credits issued by the Gold Standard.

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1 Background

Global warming and greenhouse gas emissions (GHG) are a topic of international concern, with governments, companies and industry groups now moving to establish targets for the reduction of emissions over time. As part of the Paris Agreement, Australia has committed to a 26 – 28% reduction in GHG emissions by 2030 on a 2005 baseline (Commonwealth of Australia 2017). There are also major domestic and international market drivers for improving sustainability and reducing emissions from livestock systems. One of the key drivers is the increasing pressure for producers to demonstrate sustainable and environmentally responsible practices as a prerequisite for their right to farm. This idea of a social licence to operate in a farming system describes the amount of freedom that the public and other stakeholders allow producers to exploit resources for their operation (Williams and Martin 2011)**.** If the industry does not meet community expectations, industry support and market acceptance may decline. Meat and Livestock Australia (MLA) has responded to these societal priorities for action on climate change by outlining an aspiration for the red meat industry to be carbon neutral by 2030 (CN30).

While emissions from agriculture are declining, agriculture produced an estimated 75.6 Mt CO_2-e emissions or 13.5 % of national emissions during 2018 (Commonwealth of Australia 2020a). The majority of this (51.7 Mt CO_2-e or 9.6 % of national emissions) was from enteric methane from cattle, sheep and goats. More broadly, fossil fuel energy use, emissions for the manufacture of purchased inputs, soil emissions and emissions associated with land use and direct land-use change all contribute to the overall emission profile of agricultural production. The agricultural sectors' focus on improvements in on-farm practices, landscape management and animal nutrition as well as advancements in technology and production strategies provides high potential for GHG mitigation.

Feedlots are an important part of the beef supply chain providing a high level of production efficiency and lower GHG emissions per unit of feed intake and per kilogram of liveweight gain (LWG) (emission intensity) than grazing cattle (Wiedemann 2018). In 2018, emissions from the feedlot sector contributed 5.3% of red meat emissions, 3.5% of agricultural emissions and 0.5% of national emissions (Commonwealth of Australia 2020a). Many aspects of the feedlot operation make emission mitigation more readily achievable, and consequently, feedlots have an important role in working towards the industry goal of carbon neutrality. For example, the diet of lot-fed animals can be readily manipulated, and with highly effective mitigations it is possible that enteric methane fermentation could be greatly reduced or even eliminated, with the potential added benefit of improved feed efficiency and growth rates. Reduced days on feed via increased average daily gain could also reduce emissions per head or kg beef (Hristov *et al.* 2013). With the increasing proportion of the national herd being fed in feedlots, there is an opportunity and an important responsibility for feedlots to contribute towards reduced emissions.

The growing interest in sustainable products and methods to move towards low or zero GHG emission creates the opportunity for lot feeders to differentiate themselves from competitors by marketing carbon neutral accredited beef. Prioritising carbon accounting now and investing in GHG mitigation strategies ensures market access in the future and utilises technologies that drive economic, environmental and social benefits. Outlining pathways to progress towards carbon neutrality will assist lot feeding organisations and grain-fed beef brand owners in decision making and business planning. This booklet defines carbon neutrality, how to conduct carbon accounting for a feedlot, and outlines pathways to and the economics of carbon neutrality for Australian feedlots.

1.1 Project objectives

The objectives of this project were to:

1. Develop a booklet that outlines pathways to carbon neutrality for Australian feedlot organisations available in the lead up to 2030.
2. Develop case studies on the economics of carbon neutrality for grain-fed beef brands, whole product lines and feedlot organisations.

2 Introduction to carbon accounting and neutrality for feedlots

2.1 What is carbon accounting?

2.1.1 Introduction to Greenhouse Gases (GHG)

Greenhouse gases reported under the Australian government's National GHG Inventory (also known as the National Inventory Report or NIR) include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6) and other hydrofluorocarbons and perfluorocarbons. The main emissions from agricultural production are carbon dioxide, methane and nitrous oxide. To allow for an accurate comparison between the quantity and potency of emission sources, GHG emissions are measured in carbon dioxide equivalents (CO_2-e).

The carbon cycle illustrates the flow of carbon between different carbon reservoirs on Earth. Reservoirs include carbon life forms such as plants and animals, oceans, rocks, minerals and gases in the atmosphere. Carbon is transferred between these reservoirs through processes such as respiration, decomposition, photosynthesis, livestock emissions and the combustion of fossil fuels and biosolids. The amount of carbon on the planet does not change because earth is a closed system. A balance system occurs when the carbon naturally released from reservoirs is equal to the amount of carbon that is naturally absorbed by reservoirs. However, the distribution of carbon between reservoirs can change and has been accelerated due to human impact. Particularly, the use of fossil fuels (fossil reservoirs of carbon), deforestation and soil carbon loss has created an imbalance in the carbon cycle through the increase of carbon in the atmosphere, leading to global warming. While the carbon cycle involves enormous amounts of carbon, the global warming is influenced by 'net' emissions. Typically, flows of so-called "biogenic carbon" are not counted as part of the emissions relevant for global warming. This means carbon that flows between grass, grain and livestock as part of the natural cycle does not cause a net increase in global warming. However, release of carbon from fossil fuels, deforestation or soil carbon loss, and releases of other GHGs such as nitrous oxide and methane do contribute to global warming.

All greenhouse gases are not equal; methane and nitrous oxide have much higher warming effects than carbon dioxide, and this is typically measured in terms of radiative forcing. Radiative forcing measures the immediate impact that incremental increases of GHGs have on the balance of incoming and outgoing radiation in the atmosphere (World Meteorological Organization, 1985). A positive radiation force indicates that the incoming energy is greater than the outgoing energy, whereas a negative radiation force indicates that outgoing energy is greater than incoming energy. Each gas has a different capacity to contribute to global warming. The Global Warming Potential (GWP) is a measure of cumulative radiative forcing, which aims to quantify the long-term contribution of a particular gas, to global warming. It is the global metric for assessing the equivalence of these different gases over a 100-year time period (i.e. the average contribution to global warming over the next 100 years). Using this system, the GWP_{100} value for methane used in Australia as of July 2020 is 28 (i.e. 28 times more warming potential than carbon dioxide), and the GWP_{100} value for nitrous oxide is 265 (Figure 1).

It is recognised by the industry that limitations may exist to the GWP_{100} method, particularly around how methane is handled, and work is ongoing to investigate if better ways can be found to account for methane. But at the present, the GWP_{100} method is the global standard. Methane breaks down in the atmosphere after about 10 years, and accounting for the warming effect over a much longer period (100 years) may be problematic. Several other metrics have been proposed including Global Temperature Potential (GTP) (IPCC 2014) and GWP*(Lynch *et al.* 2020) and these tend to report lower impacts for methane, though in fact they measure slightly different aspects of global warming. In the future, new methods may gain more traction and become standard practice. However, for the purposes of this manual, the standard GWP_{100} values that are used by the Australian Government and international convention have been applied. We note that these GWP_{100} values are periodically updated in response to new science, and the values here align with the Australian Government guidance as of July 2020.

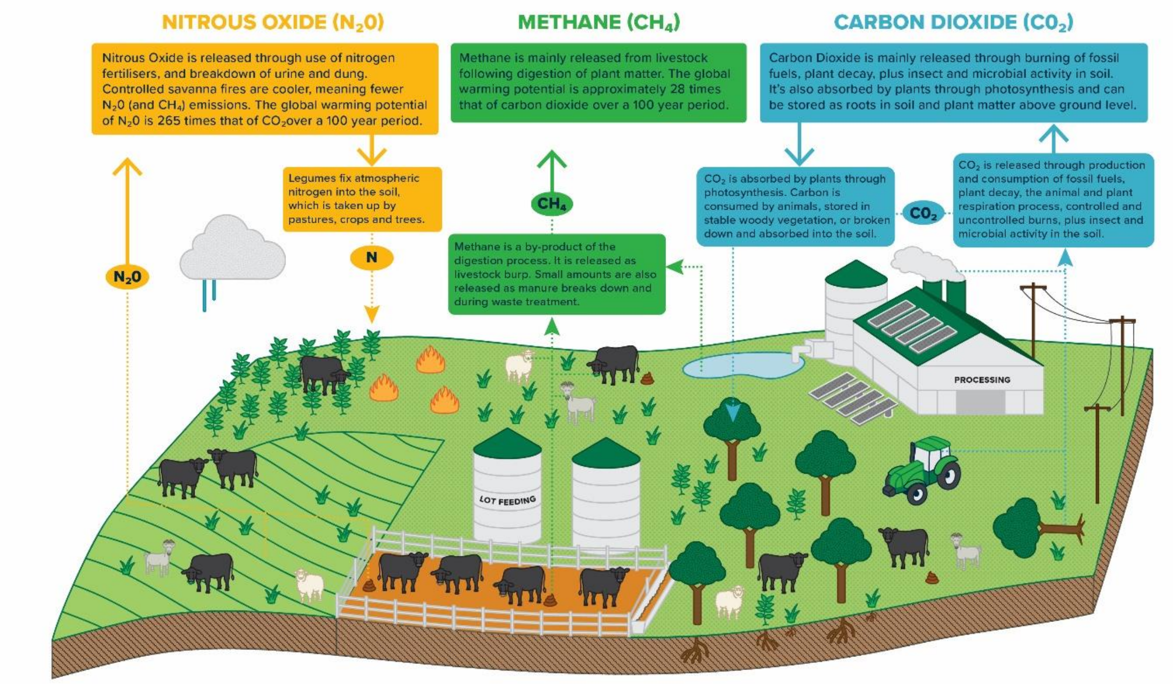


Figure 1. Sources and sinks of major greenhouse gas (GHG) emissions

2.1.2 Carbon accounting

It is both difficult and expensive to measure the amount of gas emissions (and carbon dioxide uptake) on a farm or feedlot. For this reason, carbon accounting is done through calculations, to produce an estimate of emissions and sequestration. While it is called 'carbon accounting' for simplicity, it also includes nitrogen emissions (nitrous oxide) and may be better termed "GHG accounting". In this manual, the two terms are considered synonymous. Creating a carbon account allows producers to understand how GHGs interact with the productivity of the enterprise.

Minimum standards for carbon accounting and carbon footprinting have been developed for the red meat industry to ensure consistency and minimise variation between different accounting methods (Wiedemann 2019). Standard practice is to report emissions using different classification depending on where the emissions arise and how they relate to the business. In this booklet, the framework of the GHG Protocol (Ranganathan *et al.* 2004) has been adopted, which is common in business GHG accounting.

According to the GHG Protocol (Ranganathan et al. 2004), Chapter 4, pg. 25, emissions are defined into three scopes:

- **Scope 1**: "Direct GHG emissions occur from sources that are owned or controlled by the company".
- **Scope 2**: "Accounts for GHG emissions from the generation of purchased electricity consumed by the company."
- **Scope 3**: "Are a consequence of the activities of the company but occur from sources not owned or controlled by the company. Some examples of Scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services." These can be further broken down into two sources:
  - **Upstream emissions:** from pre-feedlot sources such as the production of purchased feed, manufacture of chemicals, feeder cattle emissions and the burning of fossil fuels including the extraction, production and transport of fuel and electricity.
  - **Downstream emissions:** are post-feedlot emissions associated with the processing of cattle, including emissions from transportation, meat processing and distribution.

Emissions can also be separated into direct and indirect emissions:

- **Direct emissions** are from sources that are owned or controlled by the company.
- **Indirect emissions** are a consequence of the activities of the company but occur at sources owned or controlled by another company.

The terms **carbon accounting** and **carbon footprint** are often used interchangeably; however, there are some clear differences, depending on the livestock systems being assessed. **Carbon accounting** is the process lot feeders can use to determine their annual net GHG emissions (in tonnes of CO_2-e). This may include all emissions emitted or sequestered within the operational and organisational boundary of the farm enterprise and any stored carbon stocks on-farm (i.e. only Scope 1 and Scope 2 emissions) or may optionally include Scope 3 emissions. Scope 1 and Scope 2 emissions are the most relevant emission sources to feedlots, as these sources are within operational control of the farm and are also referred to as **business emissions**. The important difference between this and a **carbon footprint** is that inclusion of Scope 1, Scope 2 and Scope 3 emission sources is mandatory for a carbon footprint. For determining carbon neutrality, a **carbon footprint** is required under systems such as the Australian Government's Climate Active program, and under most third-party systems throughout the world.

Sources of emissions for a feedlot, separated by scope, are outlined in Figure 2.This manual will not include specific guidance for Scope 3 emissions (e.g. feed production or feeder cattle). Further information regarding this accounting process can be found in the Minimum Standards (Wiedemann 2019), the National Inventory Report (Commonwealth of Australia 2020b) and UN FAO LEAP guidelines for the environmental performance of animal feed (FAO 2016a) and large ruminant (FAO 2016b) supply chains.

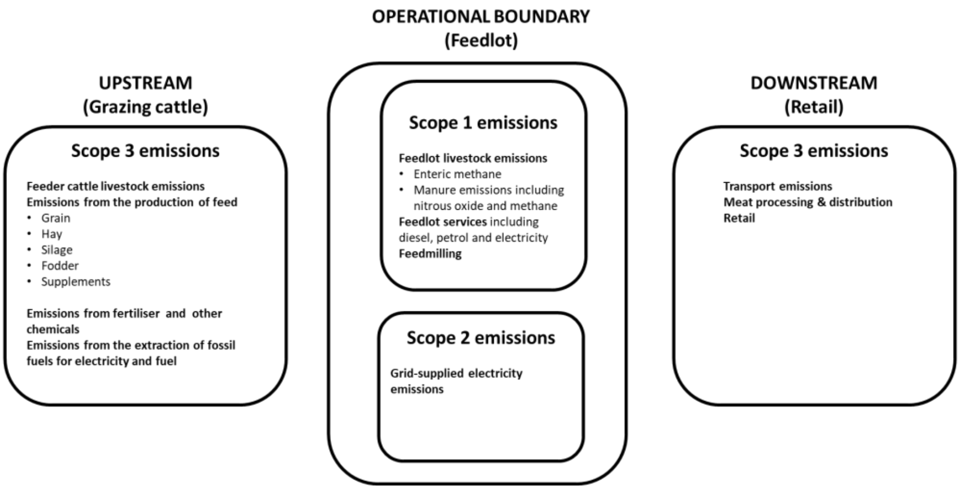


Figure 2. Examples of Scope 1, 2 and 3 emissions for a feedlot.

2.1.3 Carbon footprint

A carbon footprint examines the combined impact of all emissions produced from an organisation or for a product (i.e. an *organisation* carbon footprint, and a *product* carbon footprint). A carbon footprint includes Scope 1, Scope 2 and Scope 3 emissions. A carbon footprint is most commonly reported for a product, and in this case, it is expressed relative to output, such as kilograms of CO_2-e per kilogram of liveweight sold. A carbon footprint is defined by the International Standard ISO 14067, and sector specific guidance for cattle has been provided by the UN FAO LEAP guidelines for the environmental performance of large ruminant (FAO 2016b) and animal feed (FAO 2016a) supply chains.

2.2 What is carbon neutrality?

2.2.1 Introduction to carbon neutral

There are multiple definitions of carbon neutral, and multiple standards that are required for making claims in the market. However, each build upon the basic concept that carbon neutral is zero net release of GHG emissions into the atmosphere.

$$Carbon\ Neutral\ (CN) = Emissions - Carbon\ storage$$

Carbon neutrality can be achieved by reducing emissions and offsetting the remainder of emissions, either by generating carbon credits through carbon storage on the site (i.e. vegetation or soil carbon sequestration) or purchasing carbon credits available in the carbon market.

2.2.1.1 Climate Active Carbon neutral certification

Climate Active is managed by the Australian Government Department of Industry, Science, Energy and Resources (DISER). Climate Active certifies businesses that have credibly reached a state of carbon neutrality by measuring, reducing and offsetting their carbon emissions. Certification is available for business operations, products and services, events, buildings and precincts. To be certified, a business must meet the requirements of the Climate Active Carbon Neutral Standard. Lot feeders can obtain a Climate Active accreditation (for a product or as an organisation) if they have achieved carbon neutrality.

The standard requires the calculation of a carbon footprint, before offsetting emissions by purchasing approved carbon credits or retiring existing carbon offset credits owned by the entity. In compliance with international standards, carbon credits generated through the Emissions Reduction Fund on-farm and sold into the carbon market, cannot then be used to also offset emissions from the enterprise. The GHG Protocol Agricultural Guidance (Greenhouse Gas Protocol 2014) states that if a company sells an offset that has been generated within its organisational boundaries, then the company must remove the emission reductions from its carbon account to avoid double counting and to conform to the GHG Protocol Corporate Accounting and Reporting Standard.

There are multiple types of carbon credits that can be generated or purchased. Eligible carbon credits for the Climate Active program currently include:

1. **Australian Carbon Credit Units (ACCUs)** are regulated financial products under the Carbon Credits (Carbon Farming Initiative) Act 2011 administered by the Clean Energy Regulator through the Emissions Reduction Fund (ERF).
2. Non-ACCU offsets allowed under the Australian Government **Climate Active Carbon Neutral Standard.** These credits are issued under the Kyoto Protocol or other acknowledged international systems and are approved by Climate Active. For example, Verified Emissions Reductions (VERs) issued by the Gold Standard.

In addition to offsetting emissions, the carbon footprint may be reduced through an emissions reduction strategy. As part of Climate Active's certification, an emissions reduction strategy must be developed, implemented and made publicly available—this is included in the Public Disclosure Statement (PDS), which is completed as part of the certification. The emissions reduction strategy must include tangible actions being implemented to reduce emissions and the timeframes in which the reductions will be undertaken.

Climate Active's certification requires independent third-party to verify the carbon footprint and offset measures. Lot feeders must meet ongoing certification and reporting requirements (e.g. annual reporting) to use the Climate Active trademark on their products.

2.2.2 Other carbon neutral programs

Globally there are now a number of carbon neutral certification providers. This section describes other available accreditations:

NoCO2 Certification through the Carbon Reduction Institute
To become *NoCO2* certified, the Carbon Reduction Institute quantifies the GHG emissions by following methodologies within the World Business Council for Sustainable Development's GHG Accounting Protocol. Essentially, they follow a similar framework to the government's Climate Active accreditation, accounting for Scope 1, Scope 2 and Scope 3 emissions. The Carbon Reduction Institute, which operate in Australia, completes the carbon account, auditing, verification and certification within the company as an all-inclusive package. It is not independently verified.

International Examples: PAS 2060 Carbon neutral certification through *the* ***Carbon Trust***
Carbon Trust is an independent certification body that provides carbon neutral accreditations aligned with international standards including PAS 2060, ISO 14067 and the GHG Protocol Product Standard. Carbon Trust are a global company that provide a product or organisation carbon neutral certification that accounts for Scope 1, Scope 2 and Scope 3 emissions. The Carbon Trust only

recognises carbon credits generated through the Gold Standard, Verified Carbon Standard and Woodland Code UK for offsetting emissions. The carbon neutral certification for a product can be licenced to use the Carbon Trust's carbon neutral label on products.

The CarbonNeutral Protocol

The CarbonNeutral protocol is an independent certification body that follows a similar approach to the Australian government's Climate Active accreditation. It follows the GHG Protocol and ISO standards. It involves defining the carbon footprint and emissions boundary, measuring the GHG account based on international and national standards, creating an emissions reduction target, reducing internal emissions and purchasing offsets to balance unavoidable emissions and providing public transparency. Participants must include at least Scope 1, Scope 2, and Scope 3 upstream emission sources. Similar to the Climate Active accreditation, the Carbon Neutral Protocol requires auditing by an independent third-party to verify the carbon account.

'Carbon Neutral Brazilian Beef'

Several states of Brazil have invested in a Carbon Neutral Beef initiative. Scientists from Brazil's Agricultural Research Corporation (Embrapa) first developed the concept of carbon neutral meat in 2012. Soon after they created the 'Brazilian Association of Carbon Neutral Meat Producers' with Embrapa owning the rights to the trademarked logo 'Carbon Neutral Brazilian Beef'. To meet the guidelines developed by Embrapa, Brazilian producers have to implement an Integrated Crop-Livestock-Forest System (ICLFS) and calculate the carbon sequestration from these sources. Independent third parties conduct audits. However, few details are available regarding the methods used, and doubts have emerged about how comprehensive this is. For example, it is not clear that all scope 3 emissions are assessed (as required by all other carbon neutral certifications). Harmonisation of beef carbon neutral definitions will be required to ensure fair global trade.

3 Emission benchmarks for Australian feedlots

3.1 Major emission sources

3.1.1 Enteric methane

Beef production is often considered a high emission meat product due to the production of enteric methane from ruminant digestion. Enteric methane contributes the majority of emissions from grazing and feedlot beef production. It is a major energy loss for the animal, representing 6.5% of gross energy intake for grazing cattle, and between 3-5% for feedlot cattle (IPCC, Volume 4, Chapter 10, 2019; Moe & Tyrrell, 1979). If energy were not lost to enteric methane, this energy would be redirected to metabolisable energy. Assuming a high grain diet with gross energy of approximately 20 MJ/kg DMI, eliminating enteric methane would be equivalent to providing a 7.4% increase in metabolisable energy.

Enteric Methane Formation

In the aerobic metabolism of living cells, excess electrons and H_2 can combine with O_2 to form water, but this reaction is not possible in anaerobic environments. Anaerobic microorganisms such as ruminal bacteria, protozoa and fungi ferment dietary organic matter (OM) components (starch and plant cell wall polysaccharides, proteins and other materials) and release end-products that include volatile fatty acids (VFA), CO_2, H_2 and CH_4 (Figure 3). The process of methanogenesis allows the absorption of VFAs, the major energy source for ruminants, and releases the gases as by-products through eructation. Fermentation also occurs in the caecum and colon of ruminants, but the amount of OM fermented is usually much less than in the rumen. The amount of methane produced is influenced by the composition of the animal's diet and the quantity of feed consumed.

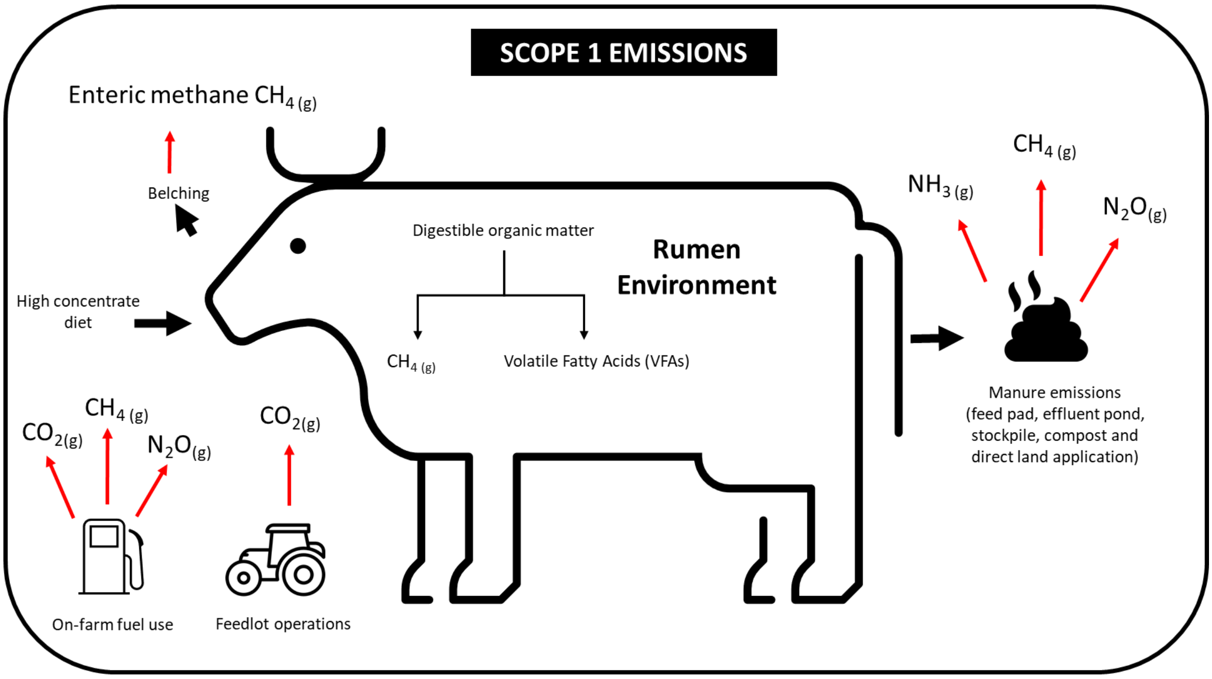


Figure 3. Scope 1 emission sources by greenhouse gas type for a feedlot

3.1.2 Manure methane emissions

Manure emissions are higher in feedlot systems than grazing systems due to the high density of animals, increasing the concentration of manure. Feed pad conditions (pH, moisture content and temperature) and compacted manure stockpiles create environments conducive to small amounts of methane production. Feedlot effluent ponds also generate methane, but total volumes are relatively low because only a very small amount (estimated to be 2%) of the manure enters the pond. None-the-less, emission rates from this small amount of manure are comparatively high.

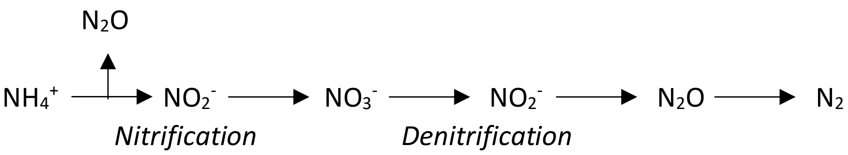
3.1.3 Nitrogen emissions

Nitrogen (N) entering the feedlot system as feed crude protein or non-protein N in the feed ration is utilised for growth and maintenance. In contrast to carbohydrates and fats, amino acids are not stored in the body, and excess N is instead excreted. Up to 90% of dietary N is excreted (Dong *et al.* 2014). To form urea, the nitrogenous end-product of protein metabolism, the N component of the amino acid is removed to leave a carbon skeleton that can be used to produce ATP (an organic compound that provides energy to drive biological processes). Nitrogen is then combined with carbon and oxygen to form urea or uric acid in the liver and is excreted in the urine. Beef cattle excrete 60 – 80% of N in urine and 20 – 40% in faeces (Varel 1997; Dong *et al.* 2014). Nitrogen in urine includes 70% urea and 30% mineralised organic compounds. Urea is readily converted to ammonia (NH_3) by urease which can be lost through volatilisation. Faecal N consists of 50% organic N (undigested feed residues, enzymes and microbes) and 50% ammonia (Mackie *et al.* 1998). Nitrogen excretion in the faeces will continue to occur even if the animal was fed an N free diet. This is because the majority of N in the faecal matter is obtained from within the body, otherwise known as Endogenous Faecal N.

Excreted N generates emissions soon after excretion, from the feed pad. The major emission is NH_3 which is not a GHG but does contribute indirectly to small amounts of nitrous oxide after the ammonia falls to land. Nitrous oxide is also generated from the feed pad in relatively small amounts.

After manure is scraped from the feed pad and is transported for stockpiling or composting, further emissions occur. Nitrous oxide production from stockpiled and composted manure varies depending on oxygen availability, substrate availability, pH and bacterial processes (Hao *et al.* 2002).

The production of N_2O from managed manures and the feed pen occurs simultaneously through nitrification and denitrification. Nitrification occurs under aerobic conditions and converts ammonium (NH_4^+) to nitrite (NO_2^-) and then to nitrate (NO_3^-) with N_2O produced as a by-product. Denitrification is the reduction of NO_3^- to nitrogen gas and occurs under anaerobic conditions.



Until recently, there have been limited Australian studies that measure direct N_2O emissions from intensive livestock systems. Nitrous oxide emission rates from the feed pad were recently reviewed, resulting in a reduction of the emission rate from 0.02 kg N_2O-N per kg of N excreted to 0.0054 kg N_2O-N per kg of N excreted (Wiedemann and Longworth 2020). In this review, it was found that manure N is not the first limiting factor driving nitrous oxide emissions from the feed pad. Consequently, reducing manure N is less likely to influence emissions than would be suggested by the emission factor. Future research to provide a prediction method based on key drivers; temperature, rainfall and manure moisture (Redding, Devereux, *et al.* 2015; Sun *et al.* 2016; Waldrip *et al.* 2016; Parker *et al.* 2018, 2019), may lead to better process knowledge and a revised emission factor or prediction method in the future.

Additionally, N_2O emissions from the manure stockpile are relatively low, largely because of the high losses of NH_3 that have already occurred on the feed pad, resulting in much less residual N to generate emissions (Bai *et al.* 2019). Large amounts of N are lost to the atmosphere from manure composting as high amounts of disturbance and aeration increase nitrification reactions (Redding, Shorten, *et al.* 2015). Hence, N_2O emissions from manure composting are higher than those from compacted stockpiles. This suggests that stockpiling is a more effective practice for GHG minimisation than composting. However, it is important to consider that composting is an effective practice to reduce the pathogen load of feedlot manure prior to use in particular markets such as horticulture and therefore may be important for other reasons.

Nitrous oxide emissions from the anaerobic effluent pond are negligible because of the anerobic conditions which are not conducive to nitrous oxide generation.

3.1.4 Other emissions

Other emissions are generated from energy use (fuel and electricity) that occur during feedlot operations and feedmilling. Additionally, scope 3 emissions from purchased feeder cattle, transportation, feed production and the extraction and production of fuel and electricity.

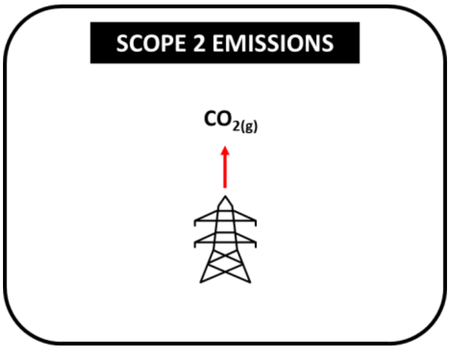


Figure 4. Scope 2 emission sources by greenhouse gas type for a feedlot

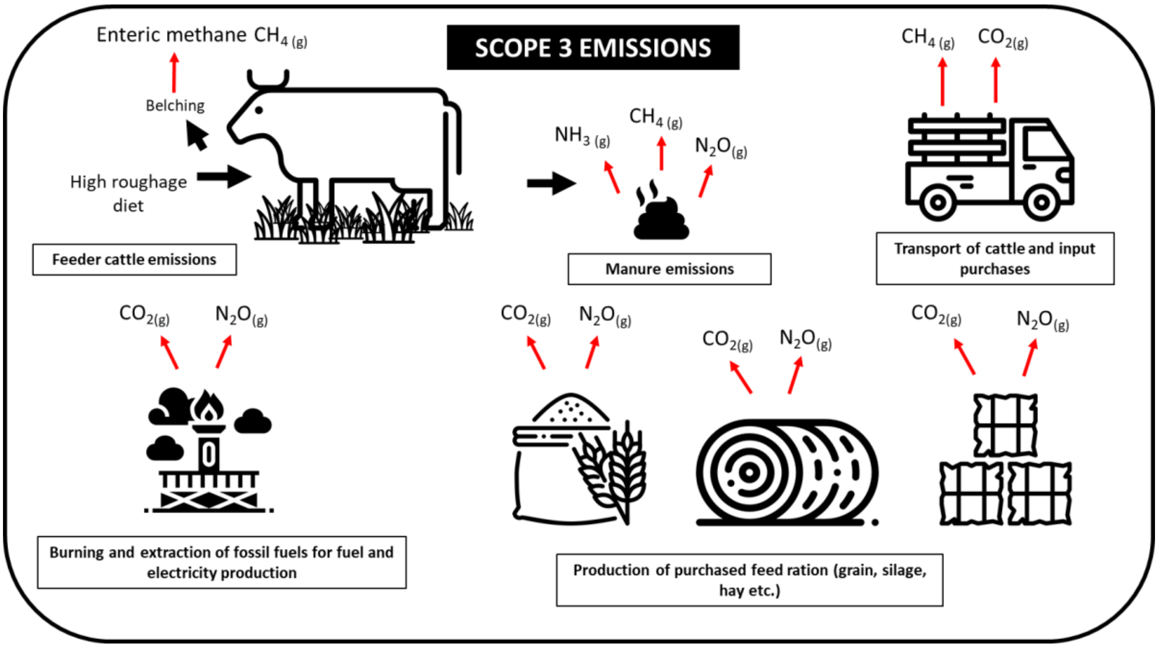


Figure 5. Scope 3 emission sources by greenhouse gas type for a feedlot

3.1.5 Emission benchmarks

Australian feedlot industry benchmarks have been adapted from the data presented in Wiedemann et al. (2017) updated to reflect new science and industry practices. New livestock performance assumptions were provided (J. McMeniman *pers. comm.*). New GHG factors were used for estimating N_2O emissions from the feed pad and the latest GWP_{100} values were applied. Three market classes were analysed: short-fed domestic heifers (*Bos taurus* breeding with hormonal growth promotant [HGP]; 66 days on feed), short-fed export steers (*Bos taurus* breeding with HGP; 110 days on feed) and long-fed export (Angus without HGP; 200 days on feed). Livestock inventory data assumptions are presented in Table 1.

Benchmarks have been reported here showing scope 1 and 2 emissions in kg CO_2-e per kg of LWG (**Error! Reference source not found.**) to illustrate the feedlot business emissions. The emission i ntensity is expressed relative to the live weight gained during the time the animal spends at the feedlot to illustrate the emissions within the feedlot boundary. **Error! Reference source not found.** s hows that the emission intensity increases as cattle spend a greater amount of time in the feedlot.

Scope 1, scope 2 and scope 3 emissions are reported in kg CO_2-e per kg of LW sold to illustrate the emissions across the full life of the animal (i.e. the full carbon footprint –Table 3). Here the emission intensity is expressed relative to liveweight sold and not live weight gain at the feedlot, as it inclusive of pre-feedlot emissions from purchased cattle, grain, fuel and transport.

The larger proportion of an animal's life occurs prior to the feedlot, and because emissions from the breeding herd are also attributed to the feeder animal, the emissions over the life of the animal are much higher prior to the feedlot than in the feedlot. The emission intensity is lower while cattle are being grain fed than while they are being grass-fed, life time emission intensity tends to decrease with increasing time on feed (Table 3). However, Wiedemann et al. (2017) found that cattle that are fed for very long periods (>300 days) with lower growth rates (1kg/day) may have higher emission intensities because feedlot finishing is less efficient over these long time periods.

Table 1 – Livestock inventory data table for a standardised 10 000 head feedlot

Activity Data	Domestic Heifers	Short-fed Export steers	Long-fed Export steers
Livestock data			
Livestock purchased (head number)	13 826	16 591	4 563
Livestock sold (head number)	13 715	16 508	4 526
Days on feed (DOF) (days)	66	110	200
Entry weight (kg)	340	425	350
Exit weight (kg)	459	645	650
Mortality (%)	0.80	0.50	0.80
Average daily gain (ADG) (kg)	1.80	2.00	1.50
Total live weight sold (kg)	6 292 512	10 647 631	2 941 900
Hot Standard Carcase Weight (HSCW) (kg/head)	238	354	357
Dressing Percentage (%)	51.97	54.85	54.93
Feed data			
Feed intake DMI (kg DM/head/day)	8.4	10.7	9.0
Dry matter digestibility (DMD) (%)	85.11	87.32	88.49
Crude Protein (CP) (% of DM)	13.80	13.59	13.00
Ash (% of DM)	4.23	4.13	4.07
Soluble Residue (% of DM)	52.38	53.34	54.30
Hemicellulose (% of DM)	18.53	17.84	17.47
Cellulose (% of DM)	6.69	6.38	6.21
Nitrogen Retention (%)*	21.66	14.54	14.47
Feed Conversion ratio (FCR)	4.67	5.35	6.00

* NIR method applied, based on N mass balance and N retention in body weight after NRC (1996).

Table 2 – Scope 1 and Scope 2 emissions for Australian domestic, short-fed export and long-fed export feedlot systems reported as an emission intensity (kg CO_2-e/kg LW gain). A hotspot analysis indicates high (red), medium (yellow-orange) and low (green) emission sources.

Emission source	Domestic	Short-fed export	Long-fed export
Scope 1			
Enteric methane	85.5%	83.1%	85.3%
Manure methane	3.6%	3.2%	2.9%
Manure direct nitrous oxide	7.5%	8.6%	8.1%
Feedlot services	0.9%	0.7%	0.9%
Feedmilling & feed production	0.9%	2.9%	1.3%
Scope 2			
Feedlot services	0.6%	0.5%	0.6%
Feedmilling & feed production	1.1%	0.9%	1.1%
Emission intensity (kg CO_2-e/kg LWG)	3.3	3.5	4.0

Table 3 – Scope 1, Scope 2 and Scope 3 emissions (full carbon footprint) for Australian domestic, mid-fed and long-fed feedlot systems reported as an emission intensity (kg CO_2-e/kg LW sold). A hotspot analysis indicates high (red), medium (yellow-orange) and low (green) emission sources.

Emission source	Domestic	Short-fed export	Long-fed export
Scope 1			
Enteric methane	7.0%	10.3%	17.1%
Manure methane	0.3%	0.4%	0.6%
Manure direct nitrous oxide	0.6%	1.1%	1.6%
Feedlot services	0.1%	0.1%	0.2%
Feedmilling & feed production	0.3%	0.4%	0.7%
Scope 2			
Feedlot services	0.0%	0.1%	0.1%
Feedmilling & feed production	0.1%	0.1%	0.2%
Scope 3			
Manure indirect nitrous oxide	0.1%	0.2%	0.3%
Feedlot services	0.0%	0.0%	0.0%
Feedmilling & feed production	3.0%	3.8%	7.2%
Transport	0.3%	0.4%	0.8%
Feeder cattle emissions	88.1%	83.2%	71.1%
Emission intensity (kg CO_2-e/kg LW sold)	10.3	9.6	9.2

Much of the industry trades cattle on a Hot Standard Carcase Weight (HSCW) basis and it seems convenient to report impacts this way. This isn't generally done in carbon accounting, because it implies all production impacts are allocated to carcase weight, ignoring hides, edible offal and other products from meat processing. Although these are fairly small, taking them into account properly when calculating impacts from meat processing reduces the overall burden to meat and is the standard practice in carbon footprinting (FAO 2016b).

4 Carbon accounting

The GHG Protocol Agricultural Guidance recommends defining a base period for the earliest appropriate period for which the company has verifiable data for Scope 1 and Scope 2 emission sources (Greenhouse Gas Protocol 2014). Base periods should not be a production season that is less than one year because an individual year will not be representative of the production system. Base periods can be calculated as a **multi-year average** or a **rolling base period**.

A multi-year average acknowledges the seasonal variability and management changes in livestock production by averaging multiple consecutive years of GHG data to determine the baseline emissions for a farm. In this case, the base period is fixed. The GHG Protocol Agricultural Guidance recommends a minimum three-year base period to balance inter-annual variability (Greenhouse Gas Protocol 2014).

Rolling base periods create a rolling average that moves forward in time with each reporting period. This means when one new year is added, the oldest year is removed. A rolling base period differs from a multi-year average by reducing the time period between the current reporting period and the base period. This method minimises the influence of long-term environmental trends such as temperature, that can affect agricultural GHG emissions. However, they do not allow reduction targets to be expressed relative to the initial fixed baseline.

4.1 Data collection

A livestock inventory is needed to provide livestock numbers for each cattle class. This should include the opening and closing numbers of cattle with livestock movements (sales, mortality and cattle remaining in the feedlot at the end of the reporting period, days on feed and feed intake). Key activity data must be obtained for each cattle market type (i.e. domestic short fed, mid fed export, long fed export) and cattle class. This data is generally readily available from livestock management software. Additionally, information about the feed ration will also be required. This includes the composition of the feedlot ration, dry matter feed intake (DMI), dry matter digestibility (DMD %),crude protein (%), soluble residue fraction, hemicellulose fraction and cellulose fraction. This data should be verifiable.

It is recommended that lot feeders develop a data management plan to manage and track their data to provide transparency and accuracy when calculating the carbon account. The Food and Agriculture Organization of the United Nations (FAO) recommends that a data management plan should include (FAO 2016b):

- a description of data collection procedures,
- data sources,
- calculation methodologies,
- data transmission, storage and backup procedures,
- quality control and review procedures for data collection, input and handling, and
- activities, data documentation and emissions calculations.

4.2 Data quality

Currently, there is no national guideline that indicates data quality requirements for emission sources. Greenhouse gas information is becoming increasingly monetised, and there needs to be clear indicators of data quality in place, so companies report reliable data. International and European guidelines provide an indication of good practices for calculating GHG emissions (Appendix 9.1). We suggest following a similar practice for estimating feedlot emissions while taking into consideration Climate Active's data hierarchy. Since purchased cattle in a feedlot is the major emission source in a cradle to gate lifecycle assessment, using regional default values for approximately 80% of the carbon footprint cannot be justified. However, since it is impractical and expensive to collect activity data from the majority of third-party suppliers, we recommend following a stratified sampling technique to sample large breeder herd suppliers. To estimate emissions from suppliers that trade large amounts of cattle, we recommend using regional default values (Appendix 9.4.4).

4.3 Modelling emissions

4.3.1 Modelling livestock emissions

Equations and default values necessary to calculate emissions from various activities associated with the feedlot are outlined in Appendix 9.3.

Livestock emission sources should be estimated using methods from the National Inventory Report (NIR) (Commonwealth of Australia 2020b). This includes:

1. Enteric methane
2. Methane manure emissions
3. Nitrous oxide emissions
4. Indirect nitrous oxide emissions

When applying factors from the NIR report, ensure the values used are representative of the feedlot cattle class (short-fed domestic, mid-fed export and long-fed export) and State or Territory.

4.3.2 Modelling other emissions

Other Scope 1 and 2 emissions from a feedlot system include fuel consumption and electricity. Upstream Scope 3 emissions include emissions from feed production, feeder cattle and emissions from extraction, production and transport of fuel and electricity.

The Climate Active Carbon Inventory (available upon registering and signing a licence agreement with Climate Active) provides **emission factors** for several common emission sources, including fuel and electricity. Many of these factors are also publically available, as published through the Australian National Greenhouse Accounts. The Climate Active Carbon Inventory does not provide emission factors for livestock and feed production emissions. A bespoke emission factor needs to be used and referenced with any assumptions or limitations. Australian emissions are assessed using the National GHG Inventory based on IPCC guidelines, and country-specific (CS) estimates categorised by animal species and class, and seasonal and geographical impacts that reflect international standards (Commonwealth of Australia 2020b). However, the National Inventory may not reflect all emission sources or the most recent knowledge available for specific emissions. Climate Active outline credible sources for bespoke emission factors in the link below. This chapter will take into consideration the most up to date science available for emission factors to estimate emission sources.

What are emission factors?
Emission factors are activity-specific coefficients used to convert an activity into an emissions equivalent (kg CO_2-e).

GHG emissions = emission factor (e.g. kg CO_2/L of diesel) × activity data (e.g. L of diesel fuel consumed)

Scope 1 and Scope 3 emission factors are recorded in CO_2-e emitted per unit of activity (livestock emissions on-farm, fuel use, etc.). Scope 2 emissions factors are recorded in CO_2-e per unit of electricity consumed.

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

Rules for handling co-products, residuals and wastes throughout the feedlot beef supply chain have been provided in Appendix 9.2 based on the Minimum Standards for Carbon Accounting and Carbon Footprints for Sheep and Beef Farms (Wiedemann 2019) and the UN FAO LEAP guidelines for the environmental performance of large ruminant (FAO 2016b) and animal feed (FAO 2016a) supply chains.

5 Reducing emissions

Mitigation strategies should be focused on reducing livestock emissions, in particular, enteric methane from rumen fermentation as it represents some 80% of scope 1 and scope 2 feedlot emissions. Some options for reducing manure emissions and impacts from energy use are also discussed.

5.1 Review of feedlot enteric methane mitigation strategies

Mitigation strategies are focused on manipulation of the rumen fermentation pathway to reduce methane production as shown in Figure 6.

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

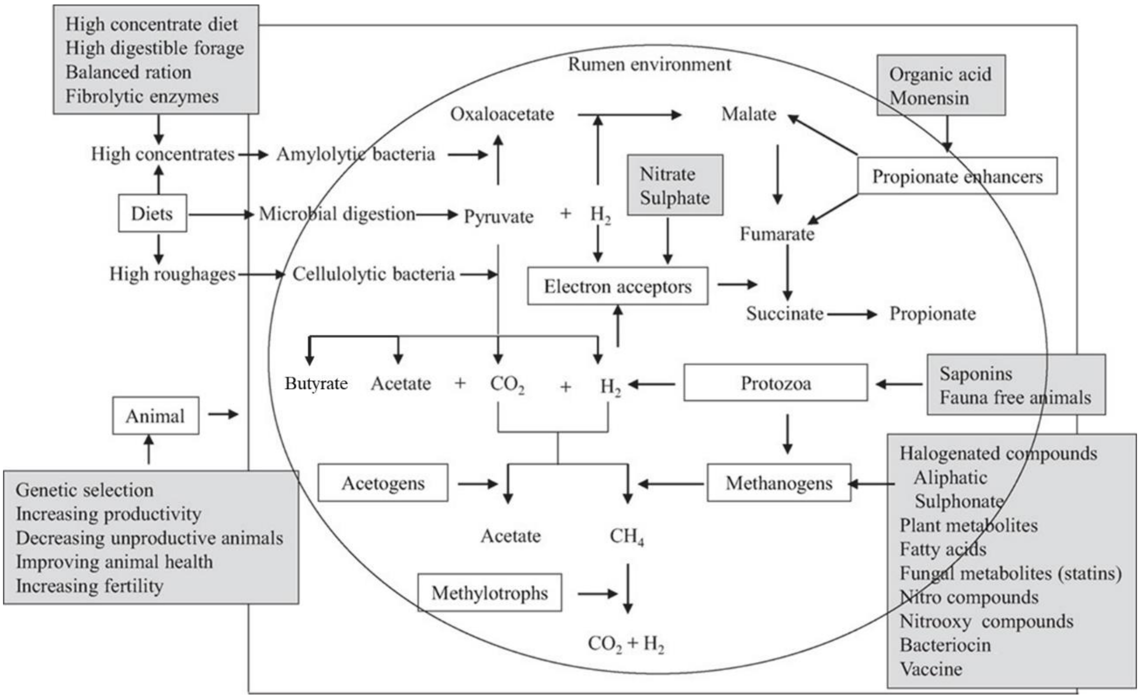


Figure 6. Possible mitigation strategies to reduce CH_4 emissions in rumen fermentation. Shaded boxes show possible mitigation targets. Adapted from Patra (2016)

5.1.1 Feed additives

Common feed additives used by the feedlot industry

Several of the most promising mitigation strategies identified for enteric methane are already practised by at least some of the feedlot industry. Many feedlots practice mitigation techniques such as the feeding of fats/oils, improved techniques for processing grain and high starch rations, and feedlots contribute to increased herd efficiency via higher lifetime growth rates. However, there may be opportunities to make small changes to feedlots to improve the mitigation response. In some cases, practices may not be applied.

Dietary oil

Feedlot rations typically include up to 7% of fats and oils on a dry matter basis to increase diet energy, ADG, feed conversion efficiency and reduce bloat. Methane production is inhibited with the addition of unsaturated fatty acids in the diet. Microorganisms in the rumen use hydrogen to hydrogenate the double bonds of unsaturated fatty acids directly inhibiting hydrogen transfer to methanogens. Lipids are found in a variety of feeds, including crushed oilseeds and whole fluffy cotton seed, and are commonly used by lot feeders. The form of fat (oil or seed), the fat source (canola, cotton seed) and the major fatty acids in the diet does not affect the relationship between dietary fat concentration and mitigation potential (Grainger and Beauchemin 2011). It is important to consider that dry matter intake may be suppressed in rations with above 10% fat content. However, many feedlot rations are well below this threshold and could be reformulated to maximise dietary oil levels for production and methane reduction benefits, though the cost-benefit of doing this would need to be considered on a case-by-case basis. Methane abatement of 10 – 25% is possible with the addition of dietary oils to the total mixed ration (Beauchemin *et al.* 2008). A 1% increase in dietary oil was found to decrease enteric methane yield by 1 g/kg DMI (Grainger and Beauchemin 2011) or approximately 4.9 % methane reduction per 1% increased oil in the ration (see **Error! Reference source not found.**). The current enteric methane calculations used in the National I nventory do not consider the contribution of dietary oil (Moe and Tyrrell 1979). Further work is required to adapt the National Inventory calculations to reflect this reduction.

Monensin

Monensin is a naturally occurring ionophore antibiotic widely used as a rumen modifier for preventing rumen acidosis in cattle fed high concentrate diets. There are four mechanisms for methane reduction by monensin:

- Monensin reduces methane production by reducing DMI by 5 – 6% and increasing feed conversion efficiency, reducing lifetime methane per kilogram of beef.
- Monensin promotes the selection of succinate forming and propionate forming bacteria to produce propionate.
- Monensin inhibits the release of H_2 from formate, selectively reducing acetate formation.
- Monensin also limits the survival of protozoa.

In theory, monensin should have a direct impact on methane reduction. However, animal response to monensin has not been consistent, with studies reporting reductions in methane emissions between 0 – 30% (Guan *et al.* 2006; Beauchemin *et al.* 2008; Grainger *et al.* 2008; Grainger and Beauchemin 2011; Duffield *et al.* 2012; Vyas, Alemu, *et al.* 2018). This range of response can be partly explained by differences in dose, duration, mode of action and diet (Duffield *et al.* 2012). A meta-analysis of monensin (32 mg/kg DMI) included in the total mix ration of beef steers reduced CH_4 emissions by 19 ± 4g/animal per day (Appuhamy *et al.* 2013). However, the methane reduction effect of monensin doesn't persist as rumen protozoal populations can adapt over time (Guan *et al.* 2006). Due to variations in mitigation response, the CH_4 mitigation effect of monensin in ruminants may be 5% (Hristov *et al.* 2013).

Prospective feed additives for methane reduction

Asparagopsis (a halogenated aliphatic compound)

Asparagopsis is a genus of red marine macroalgae which is rich and diverse in lipid and tannin content (Kinley *et al.* 2016). Previous work has evaluated the effects of 20 tropical macroalgae species in '*in vitro'* fermentation parameters (total gas production (TGP) and methane production) under incubated rumen fluid fed low-quality roughage diet (Machado *et al.* 2014). The results from Machado *et al*. (2014) showed that Asparagopsis was the most effective species in reducing total gas and methane production whilst having the least negative effect on fermentation. Bromoform and brominated halomethane are the most abundant compounds which inhibit the production of CH_4 (Machado *et al.* 2014). The suspected mode of action is through enzymatic inhibition by a reaction which reduces vitamin B_{12}. This results in reduced efficiency of the cobamide-dependent methyltransferase step, which is required for methanogenesis (Kinley *et al.* 2016).

While earlier research suggested feeding rates of up to 2% of substrate organic matter (OM) inclusion in the diet (Kinley et al., 2016; Machado et al., 2016), the latest research indicates much lower feeding rates of 0.2% of feed OM (or 0.385% of DMI), which delivered a 98% reduction in enteric methane. The study found Asparagopsis did not alter meat quality, influence consumer sensory evaluation criteria or contain residual bromoform in the meat, kidney, fat or faeces, suggesting that it would not be transferrable to the consumer. This study illustrates the possible co-benefits Asparagopsis could provide, if the results are supported by further feeding productivity trial research.

Asparagopsis is not commercially available as of September 2020. The estimated time to market may be as soon as mid 2021 according to Future feed (A Gatenby pers. comm.). No ERF methods are available for feeding Asparagopsis at the present time.

3-NOP synthetic product

3-nitrooxypropanol (3-NOP) is a synthetic product that can be added as a feed supplement for cattle (Vyas, Alemu, *et al.* 2018). 3-NOP is known to inhibit the enzyme meth-coenzyme M reductase (MCR), which is required in the last step of methanogenesis by rumen archaea (Vyas *et al.* 2014; Dijkstra *et al.* 2018). 3-NOP is degraded into two natural compounds by its own mode of action during its effect of inhibiting methane production (*pers comm.* Bird 2020) and regular supplementation is needed (Romero-Perez *et al*., 2014).

Vyas, Alemu, *et al.* (2018) found a reduction in methane by 42% and 37% with backgrounding (3-NOP at 200 mg/kg DM) and finishing (3-NOP at 125 mg/kg DM) diets respectively. This was associated with a 5% improvement in backgrounding feed efficiency and a 3% improvement in finishing efficiency. Further research by Vyas, McGinn, *et al.* (2018) showed 3-NOP inclusion rates of 100, 150 and 200 mg/kg DM in a high grain diet, reduced methane emissions by 26%, 33% and 45%, for the three doses respectively. Future research would be beneficial to confirm that higher rates, combined with typical feedlot feeding practices, will result in efficient mitigation. 3-NOP is not commercially available as of October 2020 and is awaiting approval as a registered feed ingredient. While DSM have not provided the timeline for product development, it is estimated 3-NOP could be commercially available in 2-3 years (*pers comm.* Bird 2020). The abatement potential is well established; however, no ERF method is available.

Dietary Nitrate

Nitrate is a recognised enteric methane mitigation compound, though caution is needed with respect to toxicity (McAllister et al.,1996). Leng (2008) suggested that nitrite accumulation and absorption, the reason for toxicity, may be avoided if (a) the rumen microbial population has been acclimated to nitrate, and (b) sulphur:nitrate ratios in the diet are appropriate to maintain the activity of sulphur-reducing bacteria that also play a role in reducing nitrite to ammonia. The level of nitrate provided in TMR in feedlots could be controlled, so the risk of toxicity in individual animals is more easily controlled than in grazing situations. Nitrate could be fed currently, and an ERF method is available for grazing cattle (not feedlots) to generate carbon credits.

Table 4. Enteric methane mitigation potential at various inclusion rates for Asparagopsis, 3-NOP and dietary oil

Feed Additive	%	Units	Mitigation potential	Reference
Asparagopsis	0.10%	% of DMI	9%	(Kinley *et al.* 2020)
Asparagopsis	0.19%	% of DMI	38%	(Kinley *et al.* 2020)
Asparagopsis	0.39%	% of DMI	98%	(Kinley *et al.* 2020)
3-NOP	0.010%	% of DMI	26%	(Vyas, McGinn, *et al.* 2018)
3-NOP	0.015%	% of DMI	33%	(Vyas, McGinn, *et al.* 2018)
3-NOP	0.020%	% of DMI	45%	(Vyas, McGinn, *et al.* 2018)
Dietary Oil	1.000%	% increase in total dietary oil	4.9%	(Grainger and Beauchemin 2011)*
Dietary Oil	2.000%	% increase in total dietary oil	9.8%	(Grainger and Beauchemin 2011)*
Dietary Oil	3.000%	% increase in total dietary oil	14.7%	(Grainger and Beauchemin 2011)*
Dietary Oil	4.000%	% increase in total dietary oil	19.6%	(Grainger and Beauchemin 2011)*

* For simplicity, an average of the values reported in (Grainger and Beauchemin 2011) was used.

Defaunation

Defaunation is the removal of protozoa from the rumen through dietary fatty acid supplements, chemical drenching or vaccination methods. The removal of protozoa is known to reduce CH_4 emissions, primarily through reduced H_2 availability, decreased protozoa-associated methanogen populations, alteration to the proportions of VFAs production and increased partial pressure of oxygen in the rumen (Hegarty 1999). Additionally, protozoa complete their lifecycle in the rumen rather than passing through to the small intestines to be a source of microbial protein to the animal. If protozoa are eliminated, other microbial populations could establish that are then passed to the small intestines to provide amino acids to the animal, and some populations of bacteria may use H_2 as sinks (Nguyen and Hegarty 2019). Increased microbial supply from defaunation may lead to positive effects on growth rate in animals fed poor quality roughage diets. However, there is no recent evidence on the growth benefits of defaunation on feedlot cattle. Currently, there are no defaunation methods that are safe, effective and commercially available due to issues with toxicity to other rumen microbiome and to the animal (Nguyen and Hegarty 2019). Research into other potential defaunation techniques, including plant secondary metabolites such as coconut oil, is being investigated. The major constraint to defaunation is the discovery of a small protozoal population in the omasum, which may re-infect the rumen after defaunation treatments have been applied (Nguyen and Hegarty 2019).

Other feed additives

Other potential feed additives include bacteriocins, probiotics, distiller grains, micro-algae, synthetic chemicals and natural chemicals (essential oils, yeast cultures, bacterial direct-fed microbials, enzyme feed additives, condensed tannins and plant saponins). However, the methane suppression effects of these additives in feedlots require further research. Further studies have been conducted to develop a vaccine that trigger's the animal's immune system to generate antibodies against enteric methanogens. However, there is no commercial vaccine available. The addition of sulphate and nitrate-reducing bacteria are known to compete with methanogens for H_2. However, the application of sulphate-reducing bacteria is limited due to the production of toxic hydrogen sulphide as an end product in the rumen (Islam and Lee 2019). Alternatively, nitrate and sulphate supplements could be utilised instead, with the added benefit of ammonia from nitrate reduction being a major source of N for microbial growth.

Other chemicals such as malate, fumarate and succinate are electron sinks that use H_2 to provide energy for propionate synthesis, however, are too expensive to be implemented commercially.

Few studies explore the effect of the combination of different feed additives on rumen fermentation and methane production. This is because most feed additives have multiple modes of action (e.g. monensin). Monensin used in combination with calcium ammonium nitrate may have influenced rumen microbial populations by inhibiting the growth of a nitrate reducer, which encouraged NO_2 to accumulate and formation of N_2O (Capelari *et al.* 2018). In comparison, the interaction of monensin and 3-NOP combined in a TMR were independent of each other (Vyas, Alemu, *et al.* 2018).

5.1.2 Herd management: improved growth rate

Finishing cattle on grain-based rations is less GHG intensive than grass-finished beef in many instances, because growth rates are significantly higher. The lower emission intensity is associated with higher feed conversion ratio, lower daily CH_4 emission rates, faster growth rates and hence a reduced age at slaughter and higher finished weights, resulting in lower lifetime enteric methane and manure emissions (Wiedemann *et al.* 2017). Feedlots can increase the efficacy of this process by using high growth-rate backgrounding with partial grain rations to further reduce animal lifespan. Noting these opportunities, the largest emission source for the feedlot supply chain remains in the cow-calf herd prior to feedlot entry. While feedlots cannot directly influence this, screening better feeder cattle producers could lead to lower overall emissions. For example, most feedlots have specifications around age at entry, and younger, heavier cattle will contribute to lower emissions. Cattle from higher productivity herds (higher weaning rates) will also produce lower emission cattle. Developing relationships and incentivising low emission cattle breeding may be a future strategy for proactive feedlots wanting to lower their carbon footprint.

Hormonal Growth Promotants (HGPs)

Hormonal growth promotants (HGPs) are commonly used by the feedlot industry to increase feed conversion efficiency and growth rates. They are administered to cattle through a slow-release implant and may reduce emissions by reducing DOF and age to slaughter. Basarab et al. (2012) reported that growth implants reduced the carbon footprint of Canadian calf-fed production systems by 5%. The improved average daily gain, DMI and feed conversion in response to anabolic implants depends on the type of implants, amount and duration of exposure, age of animals and combination of implants (Song and Choi 2001). Increasing feed conversion efficiency reduces the lifetime emissions of the animal.

Genomic selection

There is individual variation in methane production within herds fed the same diet, and this may be due to differences in methanogen populations among animals (Deusch *et al.* 2017). Selecting low methane emitters is limited by the difficulty of measuring CH_4 emissions from individual animals in their natural environment. Currently, phenotypic selection for animals with higher feed use efficiency or low residual feed intake (RFI) is the only feasible method. However, genomic selection provides an alternative to create estimated breeding values (EBVs) to facilitate genetic selection. Methane emissions have been shown to be a heritable and repeatable trait (Pickering *et al.* 2015). A reference population of several thousand genotyped industry-relevant animals would need to be measured for CH_4 traits and genotyped with genome-wide marker panels. It is estimated that selection for low CH_4 yield and low residual feed intake may reduce CH_4 emissions by 40 – 45% (Pickering *et al.* 2015). This would require extensive research and development.

5.2 Review of mitigation strategies for manure emissions

A substantial amount of research has focused on reducing manure emissions. This was previously reviewed extensively by Wiedemann et al. (2015) for the Australian feedlot industry. However, since this time, new research has re-assessed the emission profile from feedlot manure, revealing much lower emission rates than previously thought. As shown in section 3.1.5, manure contributes 13-14% of Scope 1 and Scope 2 emissions from feedlots, and 1-2% of the carbon footprint of finished feedlot cattle. The mechanisms to reduce these emissions are fairly limited. However, some options are as follows.

Reconfigure manure management

Emissions are generated at each stage during manure management. There may be options to eliminate stages in the manure management chain to reduce emissions. While further research is needed in this area, most research indicates that stockpiling manure will generate lower emissions than composting because stockpile conditions are less conducive to nitrous oxide production. It may also be possible to reduce emissions by directly transporting pen manure to field application, though this would depend on field emissions not increasing. It is also noted that some crops (such as horticultural field crops) require manure to be treated prior to application to manage pathogen loads and this should be considered on a case by case basis. Further research is needed around managing manure management systems.

Manure energy generation

There has been considerable interest in using manure for energy. However, most industry studies have concluded that the options are very limited. Manure can be successfully used for thermal energy processes (burning, pyrolysis) (Watts and McCabe 2015). However, the biggest limitations are high moisture content (moisture needs to be below about 20% to be most effective) and soil contamination, which leads to excess ash. Australian research by Davis et al. (2010) showed material removed from feedlot pens may contain significant amounts of soil in harvested manure, while Pratt et al. (2016) found soil contamination could be 30%.

Soil contamination is also a major problem for anaerobic digestion of manure, as is the rapid degradation of manure on the feed pad. Anaerobic digestion has been reasonably popular in dairy systems overseas and is very popular in the pig industry. However, feedlot manure has less than half the methane potential compared to pigs (Bo is 0.19 for feedlot cattle, and 0.45 for pigs). Compared to dairy, the main problem is the manure handling system; dairies typically flush manure rapidly, on concrete, resulting in high retention volatile solids and low soil contamination. It is possible to utilise covered ponds at feedlots as part of the normal effluent management system, but some key considerations need to be thought through: manure VS flows to the effluent pond are only about 2% (Watts *et al.* 2012) and ponds are sized for runoff events, meaning specialist ponds would need to be designed with pumps to get volatile solids into a covered pond. Overall energy potential is therefore limited, and application is not straight forward (Wiedemann 2013). None the less, in very large feedlots in higher rainfall climates with high effluent volumes, installation of a covered pond could be investigated further as a modest mitigation strategy that would also generate biogas that could be readily used in feed mill boilers.

5.3 Verifying mitigation - Emissions Reduction Fund (ERF) methods

The Emissions Reduction Fund is a voluntary program that provides financial incentives for companies to adopt approved methodologies to reduce their GHG emissions. Methodology determination (methods) under the ERF are the rules for estimating emission reductions to ensure they are valid strategies used in addition to normal operational procedures. There are NO verified mitigation methods for feedlots under the ERF as of October 2020. If new activities (such as 3-NOP) become technically and economically viable, suitable accounting approaches for beef – as applicable to feedlots and/or grazing - can be expected within the next few years. Alternatively, practice change may be better incentivised outside the ERF scheme, e.g. through participation in Climate Active. The pathway to implementation is still being assessed with regards to economic feasibility and potential uptake.

Below is a brief summary of the steps needed to register a mitigation project under the Emissions Reduction Fund.

1. Before registering any project, the producer needs to apply to become an Emissions Reduction Fund participant. This includes a 'Forward Abatement Estimate' which is the amount of emission reduction that the project is likely to achieve. Registering also involves a fit and proper person status and opening an ANREU account.
2. Participants may establish a carbon abatement contract to sell their ACCUs to the Clean Energy Regulator, or they may sell their credits through the secondary, private market.
3. The project needs to be undertaken according to the methodology determination of the specific project and uses the government supplied emissions calculator relevant to the project. To receive ACCUs, regular reports will need to be submitted to the Clean Energy Regulator for the registered projects, including reporting on emission reductions. The project will need to be regularly audited by an independent Category 2 Greenhouse and Energy Auditor, with a minimum of three scheduled audits across seven-plus year crediting period. General recording requirements specify that records must be kept for seven years. For livestock systems, this may include records for each herd including liveweights, age, herd movements and purchased feed as well as records of the business structure, location and management change.
4. If a contract has been established, participants must deliver ACCUs according to the agreed schedule and are paid according to the auction price. These transactions occur in ANREU and are made from your ANREU account.

5.4 Review of ERF methods

There are NO verified mitigation methods for feedlots under the ERF as of October 2020. There are ERF methods that may apply to other farm enterprises outside the feedlot operational boundary. These include:

Beef cattle herd management method

This method provides an opportunity for crediting emissions reductions from pasture-fed beef cattle by improving current management practices. This includes methods to improve productivity, eliminating unproductive animals in the herd, reducing the average age of the herd and to changing the number of animals in each livestock class. For more information, please visit this link:

> http://www.cleanenergyregulator.gov.au/ERF/Choosing-a-project-type/Opportunities-for-the-land-sector/Agricultural-methods/beef-cattle-herd-management

Feeding nitrates to beef cattle method

This method provides an opportunity for crediting emissions by supplementing nitrates instead of urea in grazing cattle. For more information, please see the link below:

> http://www.cleanenergyregulator.gov.au/ERF/Choosing-a-project-type/Opportunities-for-the-land-sector/Agricultural-methods/Reducing-greenhouse-gas-emissions-by-Feeding-Nitrates-to-Beef-Cattle

Estimating sequestration of carbon in soil using default values method

This method provides an opportunity for crediting emissions through the sequestration of soil carbon under pasture, crops or mixed farming systems. This is a model-based approach using standard parameters and emission factors and uses specific management actions including sustainable intensification, stubble retention and/or conversion to pasture. Manure and effluent application areas around feedlots may be eligible. For more information, please see the link below:

> http://www.cleanenergyregulator.gov.au/ERF/Pages/Choosing%20a%20project%20type/Opportunities%20for%20the%20land%20sector/Vegetation%20and%20sequestration%20methods/Estimating-sequestration-of-carbon-in-soil-using-default-values-model-based-soil-carbon.aspx

Measurement of soil carbon sequestration in agricultural systems method

This method provides an opportunity for crediting emissions through the sequestration of soil carbon under pasture, crops or mixed farming systems. This method involves random soil sampling in at least 3 defined Carbon Estimation Areas (CEAs) for baseline and subsequent sampling rounds to measure the change in soil carbon levels. Improved soil carbon levels may be achieved through increasing soil fertility, remediation of acidic or sodic soils, improving pasture or introducing permanent pastures, altering stocking rates, grazing rotations, no-tillage systems, stubble retention and remediation of land. Manure and effluent application areas around feedlots may be suitable locations for a soil carbon project. For more information, please see the link below:

> http://www.cleanenergyregulator.gov.au/ERF/Pages/Choosing%20a%20project%20type/Opportunities%20for%20the%20land%20sector/Agricultural%20methods/The-measurement-of-soil-carbon-sequestration-in-agricultural-systems-method.aspx

Vegetation methods

This method provides an opportunity for crediting emissions through the sequestration of carbon from the atmosphere by plants. This includes reforestation, revegetation or the protecting native forest or vegetation that is at risk of land clearing. There are a number of ERF vegetation methods that may be relevant to farming systems. For more information, please see the link below:

> http://www.cleanenergyregulator.gov.au/ERF/Choosing-a-project-type/Opportunities-for-the-land-sector/Vegetation-methods

6 Becoming carbon neutral

6.1 Climate Active certification process

The Climate Active Carbon Neutral Standard is one pathway to become certified as carbon neutral. Climate Active is administered by the Australian Government Department of Industry, Science, Energy and Resources (DISER), and has a minimum certification timeline of 3 months—from the point of project registration to acknowledgement of carbon neutrality (certification) and eligibility to make a carbon neutral (CN) claim in the market. The process often extends to 6 – 12 months when collecting the necessary primary activity data and modelling the carbon footprint (Figure 7). This chapter will focus on the guidelines for registering a Carbon Neutral Product.

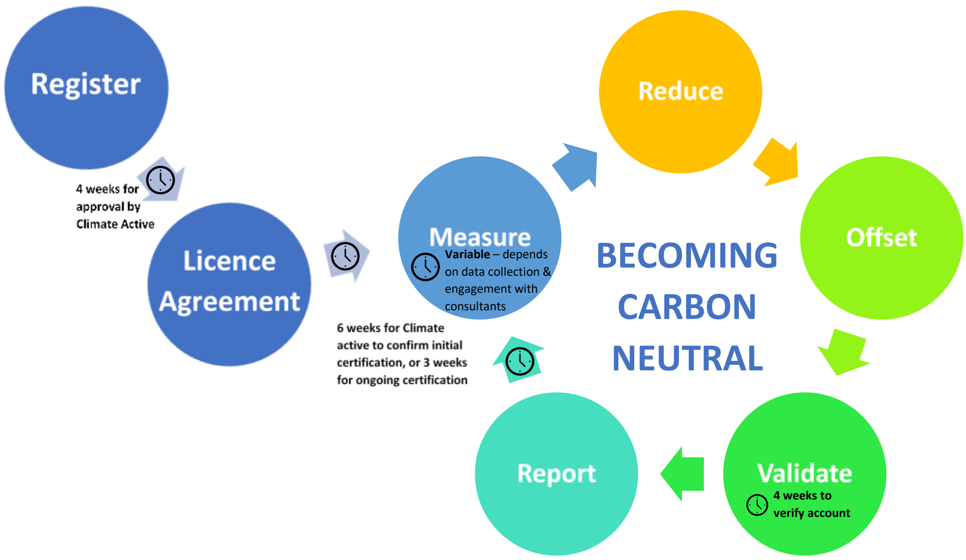


Figure 7. Steps towards carbon neutrality. Adapted from Climate Active (2020)

The steps to complete a carbon neutral product certification are summarised below:

1. **Identify** and register the project (product or organisation*)
2. Once registration is reviewed and approved by Climate Active, sign the **licencing agreement**. This ensures Climate Active is alongside your commitment to carbon neutrality and the obligations of achieving certification are fully realised.
3. **Measure** - prepare a carbon account (carbon footprint) for the baseline year. Climate Active provides all of the reporting templates, once a project has been approved in Step 2.
4. **Reduce** - develop and maintain an emissions reduction strategy. This includes nominating a timeline through to completion for the relevant activity.
5. **Offset** - purchase offset units to balance remaining emissions. Under the Climate Active Carbon Neutral Standard, offsets can be purchased for the baseline year (in arrears) or the first year of certification (forward purchasing). Eligible offset units that meet the integrity principles required by Climate Active can be found at Appendix A of the Climate Active Carbon Neutral Standard: https://www.industry.gov.au/data-and-publications/climate-active-carbon-neutral-standard-for-organisations
6. **Validate** - independent validation and verification of the carbon account to ensure accuracy.
7. **Report** - Public disclosure statement (PDS). Climate Active provide template guidance for the PDS, which once the certification process is completed, is published.

6.1.1 Register a 'Product' or an 'Organisation'

Product

The most appropriate certification for a feedlot system is typically to register a product (beef). There are multiple ways this could be approached, and this is explored in the case studies in section 7. Registration of a carbon neutral product will require, at minimum, the following details:

- Define the reference unit (e.g. kg CO_2-e per kg of boxed beef)
- Description of what will be certified (e.g. beef class/breed to processing)
- Estimation of the size of the carbon account in t CO_2-e
- Define the base year and first year to be certified
- Define the reporting year (calendar year or financial year)
- Proposed emission boundary diagram and supply chain details

The feedlot can complete this or a registered consultant can assist. Climate Active has provided a list of registered consultants that can assist with the certification and carbon accounting process: https://www.climateactive.org.au/be-climate-active/certification/register-consultants-climate-active-certification

Organisation

Alternatively, the feedlot could apply for certification as a carbon neutral organisation. However, this will generally involve a very large carbon footprint that must be offset (see section 7). As a result, this option will not be explored in detail here. For more information on carbon neutral organisation certification, please see the link below: https://www.industry.gov.au/regulations-and-standards/climate-active

6.1.2 Licence agreement

The feedlot will also need to agree to the obligations and requirements for carbon neutral certification outlined in the licencing agreement. The licence agreement includes due dates, annual licence fees and validation obligations unique to the project. The licence agreement can be accessed from the following link: https://www.industry.gov.au/sites/default/files/2020-07/licence-agreement-climate-active-carbon-neutral-standard.pdf.

The annual fees, as of CY2020 or FY2019-2020, associated with a single carbon neutral certification are provided below in Table 5.

Table 5. Annual Fees for Organisations, Products, Services and Precincts – Single Certification. Reproduced from Climate Active (2020)

Annual Emissions Within the Certification Emission Boundary	Fee (GST inclusive) (CY2020 or FY2019-2020)*
≤ 2,000t CO_2-e	$2,627.00**
2,000 ≤ 10,000t CO_2-e	$7,985.00
10,000 ≤ 80,000t CO_2-e	$13,238.00
>80,000t CO_2-e	$18,911.00

**The fees increase by 2.5% for each calendar or financial year after CY2020 or FY2019-20, unless different fees are published by the Department. This does not include fees incurred from registered consultants, independent auditors or carbon offset purchases.*

*** The licencing fee is $820.00 for a Small Organisation, otherwise as listed in Table 5.*

6.1.3 Measure - carbon account

Carbon accounting involves four key steps:

1. Establishing the emissions boundary
2. Setting a baseline year
3. Quantifying emission sources, and collecting primary activity data
4. Calculating the total carbon account (carbon footprint) for the product

Emissions Boundary

1. Define a **reference unit** for analysis of GHG emissions (e.g. kg CO_2-e/kg of LW boxed beef)
2. Two types of lifecycle assessments can be performed, and the chosen method of assessment needs to be disclosed in the product disclosure statement:
    a. A **cradle-to-grave** is a complete life cycle assessment carbon footprint (scope 1, scope 2 and upstream and downstream scope 3) of the entire life cycle of a product from before the animal enters the feedlot to the final cut of beef. This is more achievable in a vertically integrated operation that includes primary producers and meat processors.
    b. A **cradle-to-gate** is a partial life cycle assessment carbon footprint (scope 1, scope 2 and scope 3) that includes the emissions generated from the production of the animal before it enters the feedlot to the time the animal exits the feedlot. This assessment is more applicable for a feedlot operating as a standalone business.
3. Evaluate the processes and relevance grouping for the product
    a. **Attributable processes** are inputs to the system that contribute towards the final product throughout its lifecycle. These are usually sources of emissions that can be grouped into the three scopes of emissions as defined in section 2.1.2.
        i. **Quantified emission sources** contribute one per cent or more to the carbon account and must be included in the emissions boundary
        ii. **Non-quantified emission sources** contribute less than one per cent of the total carbon account but still need to be included in the emissions boundary.
    b. **Excluded emission sources** must be identified and meet the exclusion conditions. These emissions should NOT exceed five percent of the total carbon account, and are acceptable only where the following exclusion conditions are met:
        i. primary or secondary data cannot be collected,
        ii. extrapolated or proxy data cannot be determined, and
        iii. estimation of the emissions determines the process to be not material.
    c. **Non-attributable processes** are services, materials or energy flows that are not directly contributing to the final product. This includes Climate Active emissions sources listed in the template inventory and classified as 'Non-Attributable'.

Setting a baseline year

A baseline year provides an initial point for emission comparisons. Climate Active specifies that the baseline year must be within two years of the proposed first year of certification—this can be either calendar or financial year. However, Climate Active recognises that this may not provide a meaningful comparison, especially in livestock systems. Hence, a baseline year can be calculated from a multi-year average or a rolling base period, as outlined in section 9.3. Estimated data must only be used when measured data is not available and must be a conservative reflection of the feedlot system and industry practices. Uplift may also be applied to the account to ensure conservativeness. Records must be kept, and the certification independently validated.

Quantifying the emission sources

Feedlots should keep accurate records for at least seven years for an audit trail of the establishment and ongoing assessment of the carbon account.

Carbon Account (reportable emissions)

Emission estimation methods and emission factors must be displayed clearly and must include all types of GHGs. The major GHGs from a feedlot system will be CO_2, CH_4 and N_2O. Other GHGs may be emitted and should be included. For example, if commercial refrigerators were being used, refrigerant GHGs would need to be accounted for.

Actual values should be used where possible to calculate the carbon account. If this is not achievable, the Climate Active team provides an activity data hierarchy to complete the carbon account:

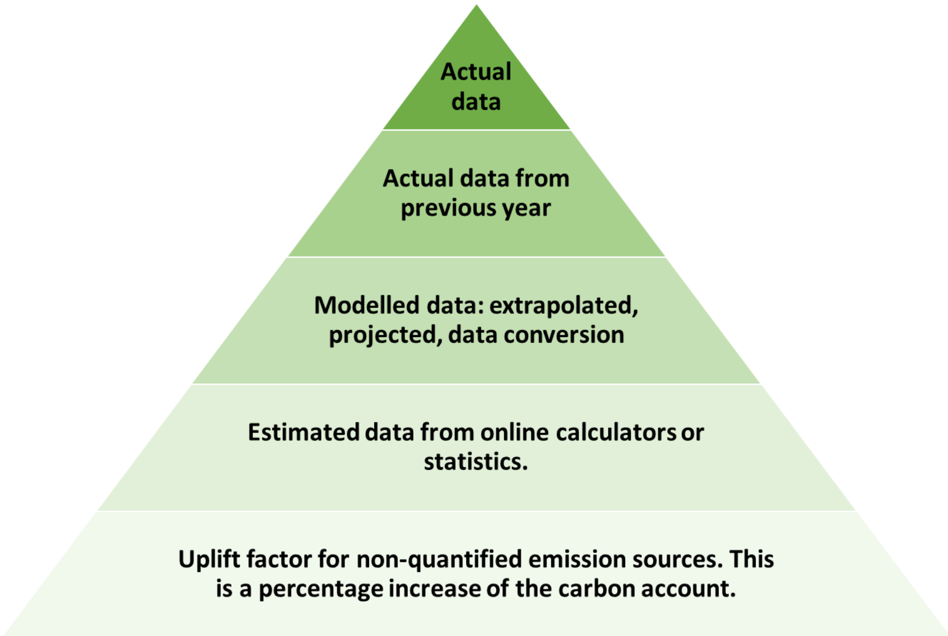


Figure 8. Activity data hierarchy. Adapted from Climate Active (2020)

Carbon accounts need to be completed annually and report on any significant changes (> ± 5 per cent) between years, including progress from previously identified emissions reduction strategies. This needs to be disclosed as part of the public disclosure statement. Additionally, changes in data availability and quality, emission factors and calculation method changes that can lead to significant differences in emissions between years, all need to be reported. Any errors over time need to be updated and the impact calculated for any affected year/s.

If an activity or product within the supply chain has been certified as carbon neutral under Climate Active, then the carbon account is considered to have zero net emissions.

Scope 1, Scope 2 and livestock related Scope 3 emissions should be determined using methods consistent with the NGGI, as outlined in section 4 of this booklet.

6.1.4 Reduce - emissions reduction strategy

The feedlot must develop and maintain an emissions reduction strategy before purchasing offsets to balance remaining emissions. However, Climate Active guidelines recognise that it may not be possible to achieve emission reductions every year. Hence, feedlots do not have to meet specific reduction targets but are required to show efforts to reduce emissions where possible and maintain dedicated timelines on the strategies proposed. Emission reductions need to be quantified and included in subsequent carbon accounts to compare changes in emissions relative to the baseline year.

6.1.5 Offset - purchase offset units

Unavoidable emissions must be offset each year through the purchase of an equivalent number of eligible offset units. The Australian Government is the largest purchaser of ACCUs through the Emissions Reduction Fund. However, voluntary carbon market participation is growing through corporate emission reduction targets and carbon neutral certifications, including Climate Active. Offset units must be reported in the Public Disclosure Statement. There are two offset methods:

1. Forward offsetting: emissions for the upcoming year are estimated and cancelled with eligible offsets at the start of the accounting year. This is validated at the end of the year to ensure the cancelled offsets is equal to the actual emissions.
2. Offsetting in arrears: offsets are purchased to cancel emissions in the year that has been completed.

Offset units may be purchased for a current claim or may be saved for a future carbon neutral claim. This allows lot feeders to be selective in their purchasing of offsets and may assist in supporting offset projects that align with their company's values and goals. Carbon credits (offset units) can be purchased through a carbon broker or carbon credit sellers. It is important to visit the ERF project register to verify project information. The Carbon Market Institute also provides project information.

The lot feeder needs to complete an **offsets registry** to cancel eligible offset units. This ensures that eligible offset units are not resold or counted twice. The registry should be publicly accessible, or further evidence will need to be provided in the public disclosure statement.

Public viewable offset registries include but are not limited to:

- Australian National Registry of Emission Units (ANREU): https://nationalregistry.cleanenergyregulator.gov.au/
- APX Carbon Registry: https://apx.com/apx-services/carbon-registries/
- Markit Registry: https://ihsmarkit.com/products/environmental-registry.html

Only offset units specified under the Climate Active Carbon Neutral Standard are eligible. Units must have a vintage later than 2012. For businesses wanting to engage in the carbon market, be aware that the global market is dynamic and can fluctuate substantially over time. It is important to consider that additional environmental and social benefits associated with a project are beginning to be valued. This may include indigenous employment, bushfire recovery and improving water quality.

- **Australian Carbon Credit Units (ACCUs):** are issued by the Clean Energy Regulator, under the Emissions Reduction Fund, and must be cancelled in the ANREU. The average price per tonne of abatement is currently $16.14 AUD (March 2020). http://www.cleanenergyregulator.gov.au/ERF/Auctions-results/march-2020
  Australia has established a high-quality carbon market (high integrity, traceability, and accountability) through the ERF. This gives the potential for internationally linked carbon markets, but the current Australian legislation prevents the transfer or trade of ACCUs internationally. The primary reason for this is that the government is in short of supply of national emission reductions. Hence, there is stability in the price of ACCUs. However, other

national crediting mechanisms have a much higher value for their national carbon credit. For example, Beijing Pilot $18.62, New Zealand $24.60, California $27.10, South Korea $50.50 and the European Union $40.78 (converted to AUD) (Carbon Market Institute 2020).

- **Certified Emissions Reduction (CERs):** issued under the Clean Development Mechanism (CDM) that are aligned with the Kyoto Protocol, excluding projects that are long term (lCERs), temporary (tCERS) or those from projects that are not consistent with criteria adopted by the EU, e.g. nuclear projects. CERs can be cancelled within any national registry. The average price per tonne of abatement was $0.15-0.24 USD for 2019 (World Bank Group 2020).
- **Removal Units (RMUs):** issued by a Kyoto Protocol country, under the CDM, and can be cancelled within any national registry. Average prices could not be established for this source.
- **Verified Emissions Reductions (VERs):** issued by the Gold Standard and must be cancelled in the Markit Registry. The average price per tonne of abatement was $4 USD for 2019 (World Bank Group 2020).
- **Verified Carbon Units (VCUs):** issued by the Verified Carbon Standard and must be cancelled in the ANREU or Markit registries. The average price per tonne of abatement was $3 USD for 2019 (World Bank Group 2020).

While companies often prefer projects that demonstrate benefits beyond emission reductions and have a high level of integrity to align with their business model, their willingness to pay a premium for these credits is limited.

Eligible offset units are often updated, and existing offsets can be removed. Before purchasing offsets, access the Department's website https://www.industry.gov.au/regulations-and-standards/climate-active to check any new updates on offset eligibility.

Drivers of price in the voluntary carbon market

Supply and demand - The price of offset units is primarily driven by supply and demand. International demand is driven by countries with Kyoto Protocol targets and countries using clean development mechanism projects to meet their national commitment. This includes demand directly from offsets purchased by governments and the private sector for compliance with domestic and industry emission targets.

Location of a project – The price of offset units is also driven by the location in which the project is initiated. Projects that take place in countries with high labour costs, high land value and have a recognised high-level integrity and compliance within industry, generally have a higher price per carbon credit. This is the case even if two different projects in separate locations comply with the same standard. For example, Australian Carbon Credit Units (ACCUs) are generally more expensive than international carbon credits as they can often be more expensive to initiate and maintain compared to developing countries. Additionally, the land value in Australia is higher and there is a high level of integrity and compliance to guarantee 25 years of commitment to emission reductions under the ERF.

Volume of offsets purchased – If a company is purchasing a large volume of carbon credits, they will often receive a cheaper price per carbon credit than if they were to purchase fewer credits.

Compliance Standard – The type of compliance standard that the project used influences the price of the carbon credit. For example, the Gold Standard has a high level of integrity as projects not only have to reduce or sequester greenhouse gas emissions, but they also have to meet at least 3 UN Sustainable Development Goals. Hence, VERs generated under the Gold Standard are often a higher price because they also deliver both positive environmental and social impacts to the community. The Verified Carbon Standard (VCS) also has a high level of integrity. In comparison, CERs developed through the Clean Development Mechanism are the oldest credits available in the carbon market. Carbon credits generated under these initial projects had less auditing and compliance requirements. Hence, CERs are the cheapest credits available in the carbon market.

Type of project (methodology) – The type of project influences the price of the carbon credit. Carbon credits generated from renewable energy projects are often cheaper than carbon credits generated from soil sequestration projects or forestry projects.

6.1.6 Validate - independent validation and auditing

An independent third-party auditor verifies the validity of the claim. This verification is required on application or if the base year requires recalculation. It includes reviewing the emission boundary, carbon accounting methodologies and calculations. This can be conducted by an environmental auditor or carbon consultant that was not the registered consultant that completed the carbon account. The cost of the independent auditor is in addition to the Climate Active accreditation fees. The cost of the independent auditor depends on the size and complexity of the carbon account and could range from $7000 – 30,000.

6.1.7 Report - public disclosure statement

An annual public disclosure statement is to be completed to communicate the feedlot's commitment and investment in emission reduction strategies and carbon offset projects. The Public Disclosure Statement needs to be signed by senior management and must be published on the feedlot's website. It is also published on the Climate Active website upon certification.

A public disclosure statement should include:

1. **Carbon neutral information**

   Organisation Description: This may include the number of suppliers, location and other information about the supply chain. It may also specify whether the product is a carbon neutral brand of beef based on meat grading or a carbon neutral line of cattle.

   Description of certification: This should include the type of carbon neutral claim (i.e. carbon neutral certification for a product). It may also include the reference unit used.

   Product process diagram: The product process diagram should specify the lifecycle assessment of the product (i.e. cradle-to-grave or cradle-to-grave) and the production supply chain.

   Emissions reduction strategy: The emission reduction strategy should target the major sources of emissions. This should include a brief description of the strategies implemented.

2. **Emissions Boundary**
   As outlined above in 6.1.3.

3. **Emissions Summary**
   The emissions summary must include the total gross and net GHG emissions of the product for the base year and current reporting period.

4. **Carbon offset**

The carbon offset strategy needs to be defined (forward or arrears). For each cancelled unit that is part of the carbon neutral claim, the following details must be specified:

- Project description
- Type of eligible offset unit

- Registry in which the offset unit is retired
- Date retired
- Serial number (hyperlink to registry with transaction record)
- Vintage
- Quantity information (tonnes, used, banked & for this report)

Additionally, to ensure complete transparency, a hyperlink to the record of the cancellation in the public registry with the date of cancellation should be included in this section of the report.

For further information, please see the Climate Active Carbon Neutral Standard for Products and Services, available from the Climate Active website or the following link:

https://www.industry.gov.au/regulations-and-standards/climate-active

OR

https://www.industry.gov.au/data-and-publications/climate-active-carbon-neutral-standard-for-products-and-services

7 Case studies

This section examines carbon neutrality for different feedlot examples. These examples are for verified carbon neutral products that could be marketed as 'carbon neutral' using the Australian Government's Climate Active program. Other carbon neutral accreditations would be similar but have not been covered here.

To make comparison easier between the different scenarios, the case studies are all based on a 10,000 head feedlot located in Queensland.

7.1 Case Study 1 - Carbon neutral feedlot

7.1.1 Introduction

This case study was completed to provide an indication of the costs and emissions associated with an entire feedlot becoming carbon neutral, to the feedlot gate. The case study feedlot sources cattle from multiple suppliers across northern Australia and New South Wales. The feedlot fed three main classes of cattle, a domestic feeding program (*Bos taurus* heifers with HGP), a short-fed export feeding program (*Bos taurus* steers with HGP) and a long-fed export feeding program (Angus steers without HGP), with a maximum of 10,000 head on feed at any one time.

7.1.2 Goals

The company that owns the feedlot wants to investigate becoming certified as a carbon neutral organisation. Along with this, the aim is that all the cattle sold to the processor will be certified as carbon neutral. To achieve this the enterprise will complete an organisation and a product carbon footprint. This case study helped explore the requirements to achieve these goals, the costs and potential market premium that would be required to cover costs of carbon neutrality.

7.1.3 Carbon account

A full assessment on all relevant GHG emissions was completed for the feedlot operation, including all emissions from Scope 1, 2 and upstream Scope 3 emissions.

Feedlot emissions
Livestock and manure emissions were determined using methods aligning with the current NIR methods as described in Chapter 4 (Commonwealth of Australia 2020b). The carbon footprint combined all emissions (i.e. pre-feedlot and feedlot emissions) produced from operations. The carbon footprint was expressed per kilogram of live weight. While the feedlot typically sells cattle on a carcase weight basis, the actual product leaving the enterprise is live weight and carbon accounting rules require using this unit to accurately describe the product (see section 9.2).

Production data for the feedlot was accessed from available records (example shown in Table 6). Livestock movements were determined from livestock inventories at the start and end of each year, transfers in and sale records. Numbers were rounded and standardised for the purposes of the case study.

Scope 3 emissions
Scope 3 emissions were determined for the quantity of feed used, feeder cattle and other minor inputs to the feedlot.

Feeder cattle were typically sourced from the same producer group each year, with an average of 100 suppliers. A stratified sampling strategy was designed that identified producers from the main source regions and provided a minimum of 25% coverage of supply chain cattle. This resulted in 25 suppliers being surveyed to identify key production parameters and model emissions from feeder cattle using NIR methods.

Table 6. Livestock inventory data for case study 1

Activity Data	Domestic Heifers	Short-fed Export steers	Long-fed Export steers
Livestock data			
Livestock purchased (head number)	13 826	16 591	4 563
Livestock sold (head number)	13 715	16 508	4 526
Days on feed (DOF) (days)	66	110	200
Entry weight (kg)	340	425	350
Exit weight (kg)	459	645	650
Mortality (%)	0.80	0.50	0.80
Average daily gain (ADG) (kg)	1.80	2.00	1.50
Total live weight sold (kg)	6 292 512	10 647 631	2 941 900
Hot Standard Carcase Weight (HSCW) (kg/head)	238	354	357
Dressing Percentage (%)	51.97	54.85	54.93
Feed data			
Feed intake DMI (kg DM/head/day)	8.4	10.7	9.0
Dry matter digestibility (DMD) (%)	85.11	87.32	88.49
Crude Protein (CP) (% of DM)	13.80	13.59	13.00
Ash (% of DM)	4.23	4.13	4.07
Soluble Residue (% of DM)	52.38	53.34	54.30
Hemicellulose (% of DM)	18.53	17.84	17.47
Cellulose (% of DM)	6.69	6.38	6.21
Nitrogen Retention (%)*	21.66	14.54	14.47
Feed Conversion ratio (FCR)	4.67	5.35	6.00

* NIR method applied, based on N mass balance and N retention in body weight after NRC (1996).

Inputs and services used for feedlot operations are provided in Table 7.

Table 7. Key activity data for case study 1

Activity Data	Units	Quantity
Energy		
Feedlot Services (Fuel)		
Diesel	L/year	45 694
Petrol	L/year	27 656
LPG	L/year	20
Feedlot Services (Electricity)		
Grid Electricity	kwH/year	148 732
Renewable Energy	kwH/year	
Feedmill (Fuel)		
Diesel (feed trucks, loaders)	L/year	72 122
Petrol	L/year	203
LPG	L/year	238 477
Feedmill (Electricity)		
Grid Electricity	kwH/year	284 671
Renewable Energy	kwH/year	
Purchased Feed Inputs used*		
Barley	t/year	4 013
Sorghum	t/year	10 558
Wheat	t/year	11 347
Maize	t/year	594
Straw	t/year	988
Cereal Hay	t/year	995
Silage	t/year	4 697
Cottonseed meal	t/year	701
White fluffy cottonseed	t/year	1 935
Canola meal	t/year	40
Molasses	t/year	1 360
Oil	t/year	346
Dry Supplement	t/year	294
Wet Supplement	t/year	1 741
Cotton Hulls	t/year	417
Transportation		
B-double (fuel transport)	tkm/year	29 986
B-double (grain)	tkm/year	6 003 739
B-double 38t load (feeder cattle)	tkm/year	4 004 631
B-double 38t load (finished cattle)	tkm/year	5 566 972
Feeder cattle - surveyed supply chain		
Domestic	no.	13 826
Short-fed Export	no.	16 591
Long-fed Export	no.	4 563
Domestic liveweight on feedlot entry	kg	340
Short-fed Export liveweight on feedlot entry	kg	425
Long-fed Export liveweight on feedlot entry	kg	350

* The commodity purchases should reflect ration consumed in the year.

Total emissions

The reportable emissions for the entire feedlot are provided in the baseline carbon account in Table 8. The emission intensity was 9.77 kg CO_2-e /kg LW sold, including scope 1, scope 2 and scope 3 emissions. Enteric methane contributed 83% of total livestock emissions from the feedlot (scope 1 and 2 emissions). Feeder cattle contributed more than 83% of total emissions.

Table 8. Baseline carbon account for case study 1

t CO2-e	Scope 1 emissions	Scope 2 emissions	Scope 3 emissions	Total	Contribution analysis
Feedlot Enteric methane	19 750			19 750	10.2%
Feedlot Manure methane	757			757	0.4%
Feedlot Manure nitrous oxide	1 937			1 937	1.0%
Feedlot Indirect nitrous oxide			373	373	0.2%
Feedlot Services	188	120	28	336	0.2%
Feedmill	749	231	74	1 053	0.5%
Feed			7 800	7 800	4.0%
Transport			816	816	0.4%
Feeder cattle emissions			161 520	161 520	83.1%
Total	23 381	351	170 611	194 343	100.0%

7.1.4 Offset requirements

For the feedlot organisation to be carbon neutral, the full carbon account of 194 343 t CO_2-e would need to be offset.

7.1.5 Cost of carbon neutrality

There are four main costs associated with becoming carbon neutral: professional services to complete the carbon account, verification fees, licence fees and the cost of offsets. Many variables influence the professional fees, and these could not be provided in detail. However, a cost estimate of between $30,000 – 50,000 may be reasonable, depending on the data collection requirements. Verification fees are also variable and may range from $7,000 – 15,000 depending on the complexity of the assessment. Licence fees are based on the size of the carbon account. The licence fees associated with the full carbon account in this case are in the order of $19,000.

Offset credits are a major cost and vary depending on the source. The feedlot has the choice of using Australian Carbon Credit Units (ACCUs) or other sources, including CERs, VERs and VCUs. The offset requirements for the whole entity are shown in Table 9.

This case study shows that it is expensive for the entire feedlot to become carbon neutral. It is more likely that the meat processor will be driving change within the market and may incentivise producers to provide a proportion of the cattle to be carbon neutral or specific lines of cattle to be carbon neutral. This is explored in further detail in case study 2 and case study 3.

Table 9. Cost to offset the full carbon footprint

Carbon Offset Summary	Abatement (t CO2-e)		ACCUs	CERs+	VERs+	VCUs+
		Price low ($USD/t) *		0.15	3.00	2.00
		Price high ($USD/t) *		0.24	9.00	8.00
		Price low ($AUD/t)	16.14	0.20	4.05	2.70
		Price high ($AUD/t)	16.14	0.32	12.16	10.81

Full carbon footprint	194 343	Cost using low price $AUD	3 136 694	39 394	787 876	525 251
		Cost using high price $AUD	3 136 694	63 030	2 363 629	2 101 004
Feedlot Emissions (Scope 1 and Scope 2)	23 732	Cost using low price $AUD	383 033	4 811	96 210	64 140
		Cost using high price $AUD	383 033	7 697	288 631	256 561
Price Premium required per kg of live weight sold**		Cost using low price $AUD	0.16	0.01	0.04	0.03
		Cost using high price $AUD	0.16	0.01	0.12	0.11

**Assumes a currency conversion rate of $1 AUD to $0.74 USD on 1 December 2020.*
+A range of carbon credit prices was determined from an analysis of drivers of carbon price and consultation with a carbon broker.
*** Offset credits are often the largest cost. This is inclusive of licence fees, project development and verification fees.*

7.2 Case Study 2 - Carbon neutral beef brand

7.2.1 Introduction

This case study investigates development of a carbon neutral brand. The feedlot selected prime retail cuts from a portion of the cattle processed each year to supply the brand and uses a service kill from a local abattoir. The feedlot expects to retail around 1000 head of beef from their domestic class of cattle for this brand, and this beef may be selected from any of the domestic cattle slaughtered. Meat entering the branded product was selected at the meat processor and could not be readily traced to individual animals through the feedlot.

Because only a portion of beef is marketed as carbon neutral, this will significantly reduce the offset requirements and reduce costs.

This case study uses the same feedlot described in case study 1.

7.2.2 Goals

This feedlot aims to develop a carbon neutral beef brand for a select portion of beef produced by the company. This allowed the company to test the consumer appeal for the product with only a small volume of beef.

7.2.3 Carbon account

The full assessment on all relevant GHG emissions completed for the feedlot operation in case study 1 (section 7.1). was used.

Feedlot emissions

Livestock emissions were calculated for 13 715 head which were sold per year through the branded program. Emissions from short-fed export cattle and long-fed export were excluded as they did not contribute to the carbon neutral branded product. The general emission calculation approach was the same as case study 1 (section 7.1).

To calculate feedlot overheads associated with the carbon neutral cattle, total overheads (fuel, electricity etc) used for the whole feedlot was divided by total head days, then multiplied by the head-days for the domestic cattle. Impacts for the feed mill were attributed to the carbon neutral cattle based on feed use, relative to total feed use at the feedlot.

Total emissions

The reportable emissions for the feedlot's domestic cattle turnoff (13,715 head) are provided in the baseline carbon account in Table 10. The emissions intensity was 10.26 kg CO_2-e /kg LW sold, including energy-related emissions and Scope 3 emissions. To determine the emissions associated with beef from the branded product, a total of 458 800 kg LW was required. For the 1000 head, at an emission intensity of 10.26 kg CO_2-e per kg of LW, total emissions were 4 709 t CO_2-e.

Table 10. Carbon account for domestic feedlot cattle.

Notes: The branded product utilised some 458,800 kg LW (1000 head) or 7.3% of emissions from the domestic cattle

t CO2-e	Scope 1 emissions	Scope 2 emissions	Scope 3 emissions	Total	Contribution Analysis
Feedlot Enteric methane	4 535			4 535	7.0%
Feedlot Manure methane	189			189	0.3%
Feedlot Manure nitrous oxide	400			400	0.6%
Feedlot Indirect nitrous oxide			77	77	0.1%
Feedlot Services	47	30	7	84	0.1%
Feedmill	187	58	18	263	0.4%
Feed			1 949	1 949	3.0%
Transport			204	204	0.3%
Feeder cattle emissions			56 879	56 879	88.1%
Total (excluding meat processing)	5 358	88	59 134	64 580	100.0%

Emissions from meat processing

For the branded product, a total of 1 000 head were processed. This was equivalent to 458 800 kg LW or 238 417 kg HSCW to provide 183 581 kg boxed beef. Meat processing inputs were collected (for the purposes of this case study, values from the literature were used), as summarised in Table 11 per 1000 kg of HSCW processed. After mass losses and allocation to co-products were accounted for, the emissions were 24.3 kg CO_2-e per kg of boxed beef.

For the volume of meat processed this contributed an additional 184 t CO2-e to the carbon account. Total emissions allocated to with boxed beef were 91.2% (after accounting for co-products) resulting in 4 460 t CO2-e

Table 11. Major inputs associated with meat processing used per 1000 kg of hot standard carcase weight processed, (Wiedemann, McGahan, Murphy, Yan, *et al.* 2015)

Major Inputs	Units	Per tonne carcase weight (beef)
Electricity	kWh	318
LPG	MJ	83
Diesel	MJ	40
Petrol	MJ	7
Coal	MJ	693
Fuel Oil	MJ	0
Natural Gas	MJ	1230

7.2.4 Offset requirements

The feedlot was focused on producing a carbon neutral brand. In the first year of launching, it was unknown how successful the brand would be. Assuming they achieved their volume target, the offset requirement associated with 183 581 kg of boxed beef was 4 460t CO_2-e.

If sales were less than this volume, carbon credits would only be required to offset the emissions from beef sold. Similarly, if sales exceeded expectations, additional offsets could be purchased. based on sales.

7.2.5 Cost of carbon neutrality

Professional and verification fees are outlined in case study 1 section 7.1.5. Licence fees are based on the size of the carbon account. In the present case study, licence fees were approximately $8000. The offset requirements for the carbon neutral brand are shown in Table 12.

Table 12. Cost comparison to offset full carbon footprint or 1000 head

Carbon Offset Summary	Abatement (t CO2-e)		ACCUs	CERs+	VERs+	VCUs+
		Price low ($USD/t) *		0.15	3.00	2.00
		Price high ($USD/t) *		0.24	9.00	8.00
		Price low ($AUD/t)	16.14	0.20	4.05	2.70
		Price high ($AUD/t)	16.14	0.32	12.16	10.81
Meat Processing	4 460	Cost using low price $AUD	71 989	904	18 082	12 055
		Cost using high price $AUD	71 989	1 447	54 246	48 219
Price Premium required per kg of branded beef sold to cover carbon offset costs**		Cost using low price $AUD	0.79	0.40	0.50	0.46
		Cost using high price $AUD	0.79	0.41	0.69	0.66

**Assumes a currency conversion rate of $1 AUD to $0.74 USD on 1 December 2020.*
+ A range of carbon credit prices was determined from an analysis of drivers of carbon price and consultation with a carbon broker.
*** Offset credits are often the largest cost. This is inclusive of licence fees, project development and verification fees.*

7.3 Case Study 3 - Carbon neutral line of cattle

7.3.1 Introduction

This case study uses the same feedlot described in case study 1. In this case, a dedicated carbon neutral branded product was developed from the long-fed cattle. The brand was established with specific suppliers to provide traceability throughout the supply chain.

7.3.2 Goals

The cattle sold as part of the long-fed program are part of a branded supply chain that intend to become carbon neutral. The branded product was developed as a premium product with lifetime traceability. The specific feeder cattle suppliers were engaged to participate in the carbon neutral project, and all cattle were supplied from these producers.

7.3.3 Carbon account

An assessment of all relevant emissions emitted from the production of the long-fed export cattle was completed, including relevant Scope 1, 2 and upstream and downstream Scope 3 emissions.

Feedlot emissions

Livestock emissions were calculated for 4 526 head which were produced per year through the branded program. Emissions from domestic and short-fed export cattle were excluded as they did not contribute to the carbon neutral branded product. The general emission calculation approach was the same as case study 1 (section 7.1), and the carbon footprint was expressed relative to the reference flow, which was a kilogram of boxed beef (kg CO_2-e per kg boxed beef).

To calculate feedlot overheads associated with the carbon neutral cattle, total overheads (fuel, electricity etc) used for the whole feedlot was divided by total head days, then multiplied by the head-days for the long-fed export branded cattle. Impacts for the feed mill were attributed to the carbon neutral cattle based on feed use, relative to total feed use at the feedlot.

Scope 3 emissions

Scope 3 emissions were determined for the quantity of feed used to produce the branded beef. Similarly, emissions from transportation were calculated based on the quantity of feed, other inputs, feeder and finished cattle required to produce the branded beef.

Feeder cattle were sourced from the same 10 producers each year. Because traceability and provenance was part of the brand, and to help reduce emissions over time, the full supplier group were brought into the project. Emissions were assessed for these farms using NIR methods and the minimum standards for carbon accounting in red meat supply chains (Wiedemann 2019).

Inputs and services used for feedlot operations are provided in Table 13.

Table 13. Key activity data for Long-fed Export cattle

Activity Data	Units	Quantity
Energy		
Feedlot Services (Fuel)		
Diesel	L/year	11 415
Petrol	L/year	6 909
LPG	L/year	5
Feedlot Services (Electricity)		
Grid Electricity	kwH/year	37 155
Renewable Energy	kwH/year	
Feedmill (Fuel)		
Diesel	L/year	18 017
Petrol	L/year	51
LPG	L/year	59 574
Feedmill (Electricity)		
Grid Electricity	kwH/year	71 114
Renewable Energy	kwH/year	
Purchased Feed Inputs		
Barley	t/year	1267
Sorghum	t/year	1459
Wheat	t/year	2869
Straw	t/year	826
Cereal Hay	t/year	27
Silage	t/year	1852
Molasses	t/year	12
Oil	t/year	15
Dry Supplement	t/year	660
Wet Supplement	t/year	294

Transportation		
B-double (fuel transport)	tkm/year	7 491
B-double (grain)	tkm/year	1 391 930
B-double 38t load (feeder cattle)	tkm/year	479 063
B-double 38t load (finished cattle)	tkm/year	823 732
Feeder cattle - surveyed supply chain		
Long-fed Export	no.	4563
Long-fed Export liveweight on feedlot entry	kg	350

The reportable emissions for this feedlot, for the branded beef, are provided in the baseline carbon account in Table 14. The emissions intensity was 9.23 kg CO_2-e /kg of LW sold.

Table 14. Carbon account associated with Long-fed Export cattle brand

t CO2-e	Scope 1 emissions	Scope 2 emissions	Scope 3 emissions	Total	Contribution Analysis
Feedlot Enteric methane	4 659			4 659	17.2%
Feedlot Manure methane	157			157	0.6%
Feedlot Manure nitrous oxide	441			441	1.6%
Feedlot Indirect nitrous oxide			85	85	0.3%
Feedlot Services	47	30	7	84	0.3%
Feedmill	187	58	18	263	1.0%
Feed			1 949	1 949	7.2%
Transport			204	204	0.8%
Feeder cattle emissions			19 322	19 322	71.1%
Total (excluding meat processing)	5 490	88	21 585	27 163	100.0%

Emissions from meat processing

For the branded product, a total of 4 526 head were processed at an average live weight of 650 kg per head, totalling 2 941 900 kg LW, equivalent to 1 615 956 kg HSCW and 1 211 967 kg boxed beef. Meat processing inputs were collected (for the purposes of this case study, values from the literature were used), as summarised in Table 11 per 1000 kg of HSCW processed. For the volume of meat processed this contributed an additional 1 212 t CO_2-e to the carbon account. Total emissions allocated to with boxed beef were 91.4% (after accounting for co-products) resulting in 25 935 t CO_2-e or 21.4 kg CO_2-e per kg of boxed beef.

7.3.4 Offset requirements

The total emissions required to be offset, associated with 1 211 967 kg of boxed beef was 25 935 t CO_2-e. Per kilogram of beef, this was 21.4 kg CO_2-e per kg boxed beef.

7.3.5 Cost of carbon neutrality

Professional and verification fees are outlined in case study 1 section 7.1.5. Licence fees are based on the size of the carbon account. In the present case study, licence fees were approximately $14 000. The offset requirements for the carbon neutral product are shown in Table 15.

Table 15. Cost comparison to offset Long-fed Export branded beef

Carbon Offset Summary	Abatement (t CO2-e)		ACCUs	CERs[+]	VERs[+]	VCUs[+]
		Price low ($USD/t) *		0.15	3.00	2.00
		Price high ($USD/t) *		0.24	9.00	8.00
		Price low ($AUD/t)	16.14	0.20	4.05	2.70
		Price high ($AUD/t)	16.14	0.32	12.16	10.81
Meat Processing	25 935	Cost using low price $AUD	418 593	5 257	105 142	70 095
		Cost using high price $AUD	418 593	8 411	315 427	280 380
Price Premium required per kg of branded beef sold to cover carbon offset costs**		Cost using low price $AUD	0.41	0.07	0.15	0.12
		Cost using high price $AUD	0.41	0.07	0.33	0.30

**Assumes a currency conversion rate of $1 AUD to $0.74 USD on 1 December 2020.*
[+] A range of carbon credit prices was determined from an analysis of drivers of carbon price and consultation with a carbon broker.
*** Offset credits are often the largest cost. This is inclusive of licence fees, project development and verification fees.*

7.4 Case Study 4 - Carbon Neutral brand with emission reduction

7.4.1 Introduction

This case study was completed for a feedlot that was interested in substantially reducing their on-site GHG emissions and developing carbon offsets. They have completed their carbon account for the baseline years (Case Study 1) and are investigating enteric methane mitigation, soil carbon and vegetation on-site carbon offset strategies. Soil carbon sequestration and vegetation projects are generally long-term strategies requiring practice changes and further accreditation via the ERF to produce ACCUs that can then be retired to claim carbon neutrality. The implications of this are examined below.

7.4.2 Goals

This feedlot aims to launch carbon offset strategies to reduce the size of their carbon account. They are interested in determining the feasibility of soil carbon and vegetation strategies and potential carbon sequestration levels.

7.4.3 Carbon account

The carbon account was established in case study 1.

7.4.4 Enteric methane mitigation options

This feedlot is interested in increasing the total dietary oil in the diet from 3% to 7%.

The addition of dietary oil at 7% of DMI (or a 4% increase from the baseline ration) was estimated to reduce enteric methane emissions from 19 749 988 t CO_2-e to 15 878 990 t CO_2-e .

Table 16. Enteric methane emissions at different inclusion rates of total dietary oil

	Inclusion rate	Mitigation Potential	Enteric methane t CO_2-e
Dietary Oil	0%*	0%	19 749 988
	1%*	4.9%	18 782 238
	2%*	9.8%	17 814 489

	3%*	14.7%	16 846 739
	4%*	19.6%	15 878 990

* % increase in total dietary oil

In the future, more effective feed additives are expected to become available. The case study here with vegetable oil, demonstrates how they would be incorporated.

7.4.5 Soil carbon sequestration

An increased concentration of carbon in soils leads to increased water holding capacity, soil fertility, soil aggregation, cation exchange capacity, and reduced susceptibility to erosion. Implementation of management options that lead to increased soil organic carbon levels also contribute to improved productivity, profitability and sustainability (Sanderman et al. 2010). The ability of soils to sequester CO_2 from the atmosphere and store it in the soil carbon pool offers potential GHG emission mitigation. There is great potential for carbon sequestration in soils as they hold the largest terrestrial store of organic carbon (Luo *et al.* 2010; Viscarra Rossel *et al.* 2014). Soils store 2 – 4 times the amount of C stored in the atmosphere and 4 times the amount of C stored in plants (Bell and Lawrence 2009). Small variations in soil carbon can lead to large carbon sequestration potential (Luo *et al*., 2010).

Australian soils are generally very low in soil organic carbon (SOC) with agricultural soils typically ranging from 0.4 – 4% SOC (Tow 2011). Soil organic carbon levels are constantly in a state of flux as they respond to environmental and management changes. Soil carbon increase is a function of the quantity of carbon added to the soil and how much is retained. Carbon generally will reach an equilibrium over time; it does not increase forever! This upper limit on the ability of soil to sequester carbon is determined by climatic conditions and soil type (Gibson *et al.* 2002; Stewart *et al.* 2008). The cycling and storage of soil carbon can be thought of as a bucket with two taps - one into the bucket and one out. The bucket represents the potential quantity of SOC that can be stored. One tap represents inputs into the soil, which contribute to increased SOC, and the other represents SOC losses (Figure 9). If the rate of carbon return to the soil is less than carbon removal from grain harvest, animal consumption of pastures, microbial decomposition and erosion, SOC will decline.

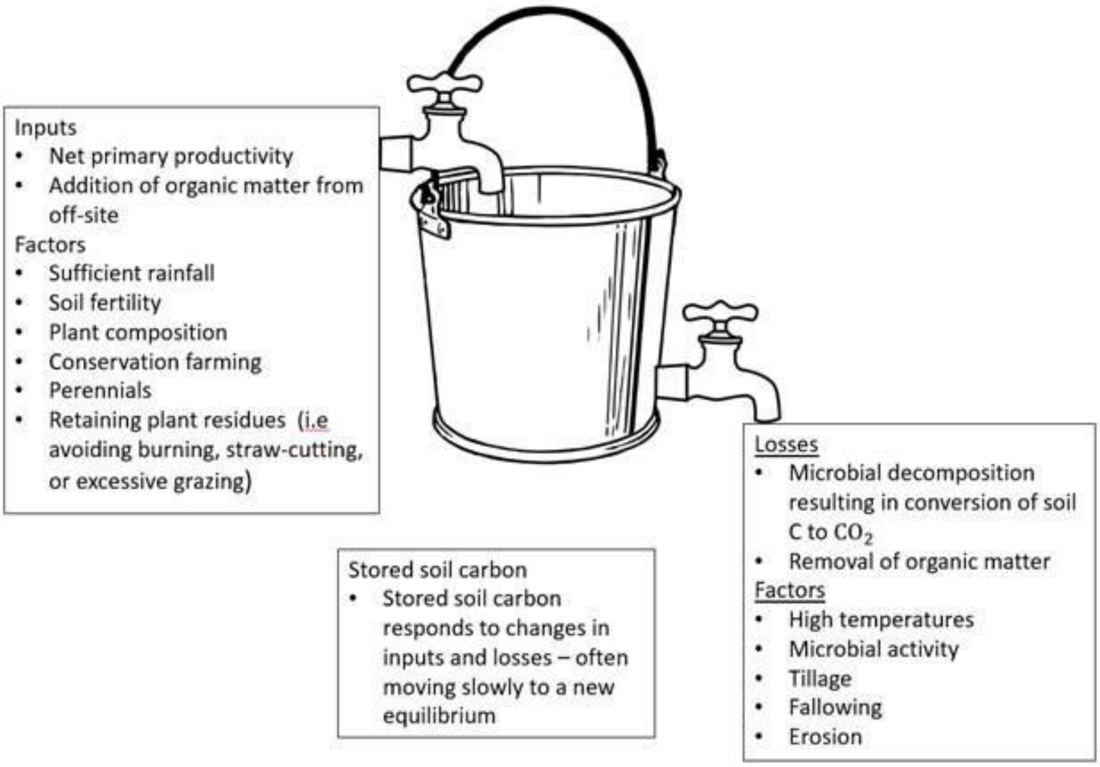


Figure 9. The storage of soil carbon is determined by potential storage, inputs into the soil and losses from the soil (reproduced from Liddicoat et al., 2010)

There is greater potential for carbon sequestration in readily degraded soils than a soil that has been under best management practices for some years, due to the large difference between the current SOC levels and the carbon saturation level or upper limit (Stewart *et al.* 2008). In Australian soils, there is a clear relationship between SOC, water availability, mean annual temperature and soil texture (Wynn *et al.* 2006). The effects of carbon sequestration are more prominent in the first 10 years of improved management systems (Lam *et al.* 2013). This is because the upper limited is most likely approached within the first 10 years and the rate of carbon retention decreases as the rate of decomposition increases (Redding, Shorten, *et al.* 2015). While it is assumed that the addition of organic material to the soil results in an increase in soil carbon, under certain conditions, added organic material can stimulate decomposition of pre-existing stored soil carbon (Fontaine *et al.* 2004). This process is known as priming (Fontaine *et al.* 2004).

Manure from feedlot pens is a large carbon source that can be used to increase SOC levels. Minimal studies exist on carbon sequestration from manure application to Australian soils. Redding et al. (2015b) examined multiple studies on manure applications and found a range of 3 to 50% soil carbon sequestration. However, manure applications may not always result in significant increases in sequestered carbon (Fontaine and Barot 2005; Fontaine *et al.* 2007). Redding et al. (2015b) applied cattle manure to a range of agricultural soils in Queensland. Carbon retention ranged from 30 – 60% of applied manure carbon. Another meta-analysis of animal applied manure found that SOC stock difference was lower in tropical climates than temperate climates (Maillard and Angers 2014). This is expected as warm tropical climates have a higher rate of decomposition and accumulate C more slowly than cooler climates. This meta-analysis did not include any Australian research. While not statistically significant, this study also found that cattle manure had higher carbon sequestration than pig and poultry manure.

This feedlot is implementing a range of improved management practices to increase their soil carbon levels under pastures used for backgrounding cattle. Preliminary soils samples confirmed that there is minimal variability across the property. Consequently, stratified sampling program was designed that could detect a 0.1% change in soil carbon levels with 95% confidence. To measure the baseline soil carbon levels on their property, soil sampling was stratified by topography and management zones based on historical soil tests. The key activity the company investigated was increasing soil carbon by adding carbon and addressing nutrient deficiencies via manure application. Initial soil sampling (0 – 30 cm) showed a mean carbon stock of 47.25 t ha^{-1}, bulk density of 1.05 g cm^{-3} and total organic carbon of 1.5%.

The feedlot produces a total of 3 820 t of manure per year (0.9 – 1.1 kg VS/head/day).

The feedlot has decided to apply 10 t ha^{-1} of stockpiled manure, three times over 5 years, to 630 ha of pasture. Assuming that applied manure is 70% dry matter, 25% of applied dry matter is carbon and 50% of applied carbon will be retained and there is additional sequestration from increased pasture growth from manure addition. The estimated rate of carbon sequestration is 0.49 t C ha^{-1} $year^{-1}$. The challenge would be measuring such a small increase in SOC because of spatial variability and analytical errors that may occur in soil sampling and laboratory measurements (Vanguelova *et al.* 2016). A large sample size would be needed to detect a true statistical difference.

Understanding that 1 tonne of carbon = 3.67 tonnes of CO_2. This equates to 1.82 t CO_2-e ha^{-1} $year^{-1}$ or 1 144 t CO_2-e per year over 630 hectares. Across 630 ha this is 5 722 t CO_2-e sequestered over 5 years before any deductions for 25-year permanency, risk reversal buffer or less emissions from livestock, synthetic fertiliser, lime, residue and/or irrigation energy use. Project ACCU yield is determined after removing project emissions from carbon sequestration. Project emissions are likely to include (but are not limited to) increased fuel use for improved pasture and manure applications, increased livestock emissions from higher stocking rates, and increased emissions associated with irrigation (energy, field nitrous oxide). Of these, livestock emissions are expected to be the largest source. With conservative estimates, soil carbon may represent as little as a 0.4% offset against the feedlot's annual emission profile (Scope 1, Scope 2 and Scope 3). This is more significant for options such as the carbon neutral branded product that is only a small fraction of the overall throughput. In this case, it may be worthwhile to investigate this option further, though a cost-benefit assessment would be beneficial to ensure it was worthwhile. This should take into account the opportunity cost of using manure rather than selling it, and the agronomic value of the manure on the pasture paddocks.

7.4.6 Vegetation carbon sequestration

Trees can sequester large amounts of CO_2 in the atmosphere, which can be used to offset GHG emissions (Ramachandran Nair *et al.* 2010; Doran-Browne *et al.* 2016). The feasibility of vegetation sequestration is largely dependent on factors such as the availability of land, rainfall, soil fertility, and the impact that tree planting has on agricultural land (Unwin and Kriedemann 2000; Doran-Browne et al. 2018). Carbon sequestration through tree planting is a long-term strategy as it requires several years of establishment to receive carbon benefits. Other benefits of tree planting include increased biodiversity, erosion and salinity control, and the provision of shelter for livestock (George *et al.* 2012; Doran-Browne *et al.* 2016). However, since the quantity of carbon stored is largely dependent on the availability of land, a significant amount of land would need to be dedicated to tree planting to offset the livestock emissions from a feedlot. The age of the tree influences the rate of carbon sequestration, species, environmental conditions (soil type, rainfall) and management

(Unwin and Kriedemann 2000; Doran-Browne et al. 2018). Although higher rates of carbon sequestration occur in new plantations, mature plantations will continue to sequester carbon over their lifetime (Unwin and Kriedemann 2000). Estimated carbon sequestration rates from tree planting range from a conservative 1 – 5 t CO_2-e ha^{-1} $year^{-1}$ (Paul *et al.* 2008; Maraseni and Cockfield 2015; Doran-Browne *et al.* 2016, 2018). This would require 1200 – 1300 seedlings planted per hectare.

This feedlot is considering common types of environmental tree plantings including windbreaks, shelterbelts and riparian buffers on land surrounding the feedlot. This is a proven carbon sequestration strategy, but the scale of the tree plantings would be a key factor in whether it would generate substantial amounts of sequestered carbon. The total land dedicated to tree planting is 50 ha and includes plantings along the driveway entrance, a riparian buffer on a nearby creek located on the property, and various windbreaks. Plausible estimates for establishment costs are approximately \$3000 ha^{-1} which is \$150 000 for the total plantation, not including a water licence or infrastructure (Polglase *et al.* 2013).

Using an annual rate of sequestration of 5 t CO_2-e ha^{-1} $year^{-1}$ the total annual C sequestration from 50 ha of planted trees was 250 t CO_2-e $year^{-1}$. This was equivalent to 0.13% of the feedlot's emission profile (Scope 1, Scope 2 and Scope 3). Hence, this feedlot would need to consider a much larger area of land dedicated to tree planting to see a significant offset against the emission profile. Following this path requires the land holder to meet the eligibility requirements outlined in the ERF methodology and ACCU yield is dependent on tree growth rates and site descriptors such as soil type, climate and region which influence the sequestration potential. The compliance costs are scale dependent. If a company were considering purchasing land for re-growth, the opportunity cost of the land would have to be evaluated.

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9 Appendix

9.1 Data Quality

Currently there is no national guideline that provides an indication of data quality requirements for emission sources. Greenhouse gas information is becoming increasingly monetised and there needs to be clear indicators on data quality in place, so companies report reliable data. The following International and European guidelines provide an indication of good practices for calculating GHG emissions. In a feedlot system, this is particularly important for accounting for emissions from feeder cattle that represent the largest source of emissions.

International Guidelines:

The GHG Protocol recommends that Scope 3 emissions sources should be reported where those sources are considered significant and can be sourced from primary or secondary data (Greenhouse Gas Protocol 2014) . Additionally, they also recommend prioritising data quality improvements for emission sources that have low data quality and high emissions. However, the GHG Protocol recognises that the quality of data from suppliers may vary and be difficult to determine. They provide guidance for collecting primary data from third-party suppliers which includes but is not limited to targeting relevant suppliers, making the data request simple or requesting specific documentation.

The Protocol Technical Guidance for Calculating Scope 3 Emissions (Greenhouse Gas Protocol 2013) provides further details to ensure data quality from scope 3 emission sources. This guidance acknowledges that companies should use methods that reduce the cost and complexity without comprising the quality of data. This follows a similar approach that was mentioned in the GHG Protocol Agricultural Guidance by applying more accurate data to large sources of emissions. They also suggest collecting data from representative samples and extrapolating these results. Sampling techniques include simple random sampling, systematic sampling and stratified sampling and the decision to use a technique should provide an accurate representation of the emission source.

The FAO LEAP Guidance (FAO 2016b) provides an international approach to the assessment of the environmental performance of large ruminant supply chains. These guidelines recognise that for agricultural systems, a large proportion of the data used will be secondary. In a feedlot system, backgrounding processes will include emissions from purchased cattle. However, primary data should, to the fullest extent feasible, be collected for all foreground processes and the main contributing sources of environmental impacts. Primary data can be directly measured, or a sample representation can be used. Any minor data gaps should be filled using the best available secondary or extrapolated data. The contribution of such data, including gaps in secondary data, should not account for more than 20 per cent of the overall contribution to each impact category considered.

The International Environmental Product Declaration (EPD) for the meat of mammals specifies that proxy data must not exceed 10% of the overall environmental impact. The representativeness of generic data should be better than 5% of the environmental impact of fully representative data.

9.2 Allocation of impacts between multiple products on-farm for reporting CF

Rules for handling co-products, residuals and wastes throughout the feedlot beef supply chain have been provided based on the Minimum Standards for Carbon Accounting and Carbon Footprints for

Sheep and Beef Farms (Wiedemann 2019) and the UN FAO LEAP guidelines for the environmental performance of large ruminant (FAO 2016b) and animal feed (FAO 2016a) supply chains.

Allocation should follow the basic guidance from ISO 14044, favouring that allocation is first avoided if possible, then achieved based on 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 based on total feed intake (effectively stocking rate - i.e. dry sheep equivalents).

OR "If the activities, inputs or emissions cannot be separated, the preferred method to account for multi-functional processes and co-products shall be a biophysical approach based on feed intake associated with the different animal species or co-products".

For dividing overheads between cropping and livestock, this can be done based on the total gross value ($) of production from the farm.

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

1. Allocation is not required between liveweight from different classes of livestock (i.e. steers vs cull cows) leaving the finishing stage for slaughter. All animals "are considered equivalent and considered on a liveweight basis", according to the generalised guidance from FAO (2016b) Section 9.3.1, pg. 51. All liveweight is to be summed.
2. Manure can be classified as a co-product, waste or a residual.
   According to the generalised guidance from FAO (2016b) Section 9.3.1, pg. 54, manure is considered a **co-product** when it is a valuable output of the farm. FAO (2016b) state "If the system of manure production cannot be separated from the animal production system, then the full supply chain emissions to the farm gate shall be shared by all co-products." A biophysical approach should be applied based on the energy for digestion that must be expended by the animal to utilise the nutrients and create the manure.
   Manure is considered a **residual** when it has "no value at the system boundary". In this situation, "emissions associated with manure management up to the point of field application are assigned to the animal system, and emissions from the field are assigned to the crop production system".
   "Manure is classified as waste generally only in two situations: when it is disposed of by landfill, incineration without energy recovery, or sent to a treatment facility; and when it is applied in excess of crop nutrient requirements. In the first case, all on-farm emissions shall be assigned to the animal product(s). However, in the second case, the fraction of manure applied to meet crop nutrient requirements should be considered as a residual as described above."
3. By-products, residuals and waste products fed to cattle
   We determined the product that was a residual or waste from other systems, again according to guidance from (FAO 2016a). Where materials were a residual or waste (typically defined by the product being provided to the farmer at no cost), it was assumed to be supplied with no environmental burden. Based on FAO (2016a) pg. 41, economic allocation was chosen as the preferred method for allocation between crop co-products that have an economic value (i.e. they are not residuals or waste products). The average economic value was estimated over 5-year time frame.

4. During primary meat processing, liveweight is processed into carcase weight, and a range of co-products are produced including edible offal, hides, pet food, rendering products and potentially other products. At the meat processing plant, "all products edible by humans from the supply chain are considered as equivalent, and other products should be classified in groups according to function or market (e.g. pet foods or livestock feed, tallow for biodiesel and hides for leather)", according to the generalised guidance from FAO (2016b) Section 9.3.2, pg. 56. Rendering products are also produced. Economic allocation shall be applied using the following categorisation of slaughter products

    - Fresh meat (allocation on the basis of average price of full package)
    - Other Food grade products (allocation on the basis of average price of package)
    - Other products (no allocation)(FAO 2016b).

   During further processing of carcases, meat and bone are separated, and the bone fraction is sent to rendering where it is typically made into meat and bone meal. In accordance with the generalised guidance from FAO, (2016b), this is treated as a residual with no burden allocated to the rendering material.

9.3 Modelling livestock emissions

9.3.1 Emission estimation methods – feed intake

Feed intake for each cattle class should be ascertained from feedlot records as actual values may differ from estimates using the NIR feed intake model. Alternatively, feed intake estimates can be determined using NIR feed intake model. See section 5.3.3.3, pg. 295, and Appendix 5.C.2 of the NIR (Commonwealth of Australia 2020b).

Example:

Scenario - Liveweight of steers sold for the **domestic market** in a QLD feedlot is 450kg. The mean days on feed (DOF) was 75 days. The total head turnover per year was 20,000 steers.

The reported dry matter feed intake was **9.0 kg DM/head/day.** Alternatively, predicted feed intake using the NIR method was as follows. Dietary net energy concentration was 8.4 MJ/kg. This value was obtained from Appendix 5.C.2 of the NIR for domestic cattle.

Feed Intake (I):

$$\text{I} = 450^{0.75}[(0.2444 \times 8.4 - 0.0111 \times 8.4^2 - 0.472)/8.4] = 9.3 \text{ kg DM/head/day}$$

9.3.2 Emission estimation methods - enteric methane

Enteric methane is currently calculated using a dated method in the NIR, which is described as follows.

Daily methane yields (Y) MJ CH_4/head/day:

$$Y = 3.406 + 0.510\,SR + 1.736\,H + 2.648\,C$$

Where:

SR = intake of soluble residue (kg/day)

H = intake of hemicellulose (kg/day)

C = intake of cellulose (kg/day)

Example:

The soluble residue (SR), hemicellulose (H) and cellulose (C) are assumed to be 0.62, 0.10, 0.05, respectively. These values were obtained from Appendix 5.C.2 of the NIR for domestic cattle (Commonwealth of Australia 2020b) but can be re-calculated by a nutritionist for a specific ration. These values are multiplied by the dry matter feed intake (I) using the reported value of (9.0 kg DM/head/day), to determine the proportion of the diet that contains each substrate.

i.e. $Y = 3.406 + 0.510SRI + 1.736HI + 2.648CI$

Hence, daily methane yields (Y):

$$Y = 3.406 + (0.510 \times 0.62 \times 9.0) + (1.736 \times 0.10 \times 9.0) + (2.648 \times 0.05 \times 9.0)$$

$$= \mathbf{9.0\ MJ\ CH_4/head/day}$$

Total daily methane production (M_1) kg CH_4/head/day

$M_1 = Y / F$

Where:

Y = daily methane yields (MJ CH_4/head/day) calculated above.

F = 55.22 MJ/kg CH_4 (Commonwealth of Australia, 2020)

Example

Daily methane yields (Y) are 9.0 MJ CH_4/head/day as calculated above.

Hence, daily methane production (M_1):

$$M_1 = 9.0/55.22 = \mathbf{0.16\ kg\ CH_4/head/day}$$

Annual enteric methane production (kg CH_4) for all classes of feedlot cattle

E_1 = total head days x M_1

Where:

Total head days = total turnoff x days on feed

M_1 = daily methane production (kg/head/day) calculated above in 3.1.2.

Example

Total head days is 1 500 000 and methane production (M_1) is 0.16 kg/head/day as calculated above.

Hence, annual enteric methane production (M_1):

$$E_1 = 0.16 \times 1\ 500\ 000 = \mathbf{240\ 000\ kg\ CH_4}$$

9.3.3 Emission estimation methods - methane manure emission

Manure volatile solids (VS) kg/head/day:

$$VS = I \times (1 - DMD) \times (1 - A)$$

Where:

I = feed intake (kg DM/head/day)

DMD = digestibility expressed as a fraction

A = Ash content of manure expressed as a fraction (16%)

Example

The reported dry matter feed intake was 9.0 kg DM/head/day and the dry matter digestibility of 81%.

Hence, manure volatile solids (VS):

$$\text{VS} = 9.0 \times (1 - 0.81) \times (1 - 0.16) = \mathbf{1.4 \text{ kg/head/day}}$$

Methane production from manure (M_2) kg/head/day:

$$M_2 = VS \times B_O \times iMCF \times \rho$$

Where:

VS = manure volatile solids (kg/head/day) as calculated above.

B_O = emissions potential (0.19m^3 CH_4/kg VS)

iMCF = integrated methane conversion factor for feedlot cattle in each state. Appendix 5.C.2 of the NIR (Commonwealth of Australia, 2020)

ρ = density of methane (0.6784 kg/m^3)

Example

Manure volatile solids are 1.4 kg/head/day as calculated above. The iMCF for QLD is 0.04023. This value was obtained from Appendix 5.C.2 (Commonwealth of Australia 2020b)**.**

Hence, methane from manure (M_2):

$$M_2 = 1.4 \times 0.19 \times 0.04023 \times 0.6784 = \mathbf{0.007 \text{ kg/head/day}}$$

Annual methane production from manure (kg CH_4) for all classes of feedlot cattle.

The NIR multiples emissions(kg/head/day) by number of cattle as an annual equivalent by 365 days. However, it is more practical for a feedlot to multiply emissions (kg/head/day) by total head days.

$$E_2 = \textit{total head days} \times M_2$$

Where:

Total head days = total turnoff x days on feed

M_2 = daily methane production from manure (kg/head/day) calculated above.

Example

Total head days is 1 500 000 and methane production (M_2) is 0.007 kg/head/ day as calculated above.

Hence, annual methane production for manure (M_2):

$$E_2 = 0.007 \times 1\,500\,000 = \mathbf{10\,500\ kg\ CH_4}$$

9.3.4 Emission estimation methods - nitrous oxide emissions

Nitrogen Intake (NI) kg/head/day:

$$NI = I \times CP / 6.25$$

Where:

I = feed intake (kg DM/head/day)

CP = crude protein content of feed expressed as a fraction

6.25 = factor for converting crude protein into nitrogen

Example

Feed Intake (I) is 9.0 kg DM/head/day. Crude protein is 13.4%.

Hence, nitrogen intake (NI):

$$\text{NI} = 9.0 \times 0.134/6.25 = \mathbf{0.19}\ \text{kg/head/day}$$

Nitrogen Excretion (NE) kg/head/day:

$$NE = NI \times (1 - NR)$$

Where:

NI = nitrogen intake (kg/head/day) as calculated above

NR = nitrogen retention expressed as a fraction of intake

Example
Nitrogen intake (I) is 0.19 kg /head/day as calculated above. Nitrogen retention value is 20.4. This value was obtained from Appendix 5.C.2 of the NIR (Commonwealth of Australia 2020b) for domestic cattle.

Hence, nitrogen excretion (NE):

$$\text{NE} = 0.19 \times (1 - 0.204) = \mathbf{0.15}\ \text{kg/head/day}$$

Total direct emissions of nitrous oxide (Total_{MMS}):

$$Total_{MMS} = total\ head\ days \times iNOF \times NE \times C_g$$

Where:

Total head days = total turnoff x days on feed

iNOF = integrated N_2O emissions factor for each feedlot class and state Appendix 5.C.3 of the NIR

NE = nitrogen excretion (kg/head/day) calculated above.

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Example
Total head days is 1 500 000 and nitrogen excretion (NE) is 0.15 kg/head/day as calculated above. iNOF is 0.008.

Hence, the total direct emissions of nitrous oxide (Total_{MMS}):

$$\text{Total}_{MMS} = 1\ 500\ 000 \times 0.008 \times 0.15 \times \frac{44}{28} = 2\ 829\ N_2O\ \text{kg/year}$$

Mass of feedlot waste ammonia volatilised (MN_{ATMOS}):

$$MN_{ATMOS} = total\ head\ days \times NE \times iFracGASM_{MMS}$$

Where:

Total head days = total turnoff x days on feed

NE = nitrogen excretion (kg/head/day) calculated above in 9.3.4.

$iFracGASM_{MMS}$ = integrated fraction of N volatilised from feedlot cattle. Appendix 5.C.3 of the NIR (Commonwealth of Australia, 2020)

9.3.5 Emission estimation methods - indirect emissions

Example:

Total head days is 1 500 000. Nitrogen excretion (NE) is 0.15 kg/head/day as calculated above. $iFracGASM_{MMS}$ is 0.71032.

Hence, the annual mass of ammonia volatilisation (MN_{ATMOS}):

$$MN_{ATMOS} = 1\ 500\ 000 \times 0.15 \times 0.71032 = 159\ 822 \text{ kg N}$$

Annual emissions from atmospheric deposition (kg N):

$$E = MN_{ATMOS} \times EF \times C_g$$

Where:

MN_{ATMOS} = mass of ammonia volatilised (kg N) calculated above.

EF = 0.002 (Gg N_2O-N/Gg N) (Inorganic fertiliser EF for non-irrigated cropping - Table 5.24 of the NIR (Commonwealth of Australia, 2020).

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass.

Example

Mass of ammonia volatilised (MN_{ATMOS}) is 213 096 kg N as calculated above.

Hence, annual emissions from atmospheric deposition (E):

$$E = 159\ 822 \times 0.002 \times \frac{44}{28} = 502 \text{ kg } N_2O$$

9.3.6 Summary of livestock emissions and methods

Table 17. Reportable livestock emissions within feedlot boundary

Scope	Emission Source	Source of Activity Data	Methodology Reference	Emission estimation method	Activity data	T CO_2-e
1	Enteric methane	Actual Values OR Default Values*	NIR 2018	$I=W^{0.75}[0(0.2444NE_{ma}-0.0111NE_{ma}^2-0.472)/NE_{ma}]$ $Y=3.406+0.510\ SR+1.736\ H+2.648\ C$ $M_1=Y/F$	Herd numbers & LWs from livestock inventory data	6 720
1	Manure methane	Actual Values OR Default Values*	NIR 2018	$VS=I\times(1-DMD)\times(1-A)$ $M_2=VS\times B_O\times iMCF\times\rho$	Herd numbers as above. Feed DMD	294
1	Manure nitrous oxide	Actual Values OR Default Values*	NIR 2018	$NI=I\times CP/6.25$ $NE=NI\times(1-NR)$	Feed CP	749
3	Indirect nitrous oxide, atmospheric deposition	Actual Values OR Default Values*	NIR 2018	$MN_{ATMOS}=NE\times iFracGASM_{MMS}$ $E=MN_{ATMOS}\times EF\times Cg$	Herd numbers as above, feed intake	133

**Default values are sourced from the NIR* (Commonwealth of Australia 2020b).

9.4 Modelling other emissions

9.4.1 Emissions estimation methods - fuel

To determine emissions, lot feeders need records of the quantity of fuel consumed per annum, for each fuel type. Electricity is either sourced from the state grid or renewable energy. Lot feeders need records of their annual electricity use in kilowatt-hours (kWh). The method detailed below can be used to estimate emissions from fuel or a similar tool can be found in the Climate Active Carbon Inventory. The carbon content of the fuel source will determine the amount of CO_2 emissions from combustion. Stationary energy is considered any off-road fuel sources (Table 18). Transport energy is considered on-road fuel sources. Scope 3 emission factors are used to estimate emissions from the upstream burning of fossil fuels, including the extraction, production and transport of fuel (Table 18).

The quantity of fuel used for feedlot practices needs to be accurately recorded to pass auditing for carbon neutral accreditation purposes. Annual consumption of fuel should be obtained from records kept for tax purposes. Examples of records used to determine the type, date and quantity for fuel acquired include invoices, receipts, fuel card statements, fuel supplier statements and bank statements. To separate fuel usage for the feedlot from other enterprises on farm refer to vehicle or equipment maintenance records, odometer readings, logbooks, production records, fuel usage reports, engine hours or provide details of any formulas or assumptions used. This is similar to the records used to support your fuel tax credit claim.

Annual fuel combustion emissions:

$$E = Q \times EF$$

Where:

E = emissions of fuel type (t $CO_{2\text{-}e}$/annum)

Q = quantity of fuel type combusted (kL)

EF = emission factor (t $CO_{2\text{-}e}$/kL)

Table 18. Emission factors for major fuel types for stationary energy purposes (non-transport), transport vehicles (post-2004) and heavy vehicles. Adapted from Commonwealth of Australia (2019)

Fuel combusted	Scope 1 Emission Factor t CO_2-e / kL	Scope 3 Emission Factor t CO_2-e / kL	Full carbon footprint (Scope 1, 2, 3) t CO_2-e / kL
Stationary energy purposes			
Diesel oil	2.71	0.14	2.85
Petrol	2.32	0.12	2.44
Fuel oil	2.93	0.14	3.07
Liquified petroleum gas (LPG)	1.56	0.09	1.65
Transport vehicles (post-2004)			
Diesel oil	2.72	0.14	2.86
Petrol	2.31	0.12	2.44
Fuel oil	2.95	0.14	3.09
Liquified petroleum gas (LPG)	1.60	0.09	1.69

Adapted from Commonwealth of Australia (2019)

Example

A feedlot consumes 180kL of diesel per annum for non-transport purposes. Scope 1 emissions of GHGs (carbon dioxide, methane and nitrous oxide) in tonnes of CO2-e are estimated as follows:

GHG Emissions:

E = $180 \times 2.71 = 487.75$

Total GHG emissions from diesel = 487.75 t CO_2-e/annum

9.4.2 Emissions estimation methods - electricity

In a feedlot system, water pumping and feed milling are typically the largest sources of electricity consumption. Scope 2 emission factors for electricity are used to estimate the emissions from the consumption of purchased electricity from the main electricity grid and the loss of electricity during the distribution network. Emissions from on-grid electricity consumption are based on emission factors specific to the State or Territory. Scope 3 emission factors are used to estimate emissions from the upstream burning of fossil fuels, including the extraction, production and transport of electricity (
Table **19**). Renewable electricity has an emission factor of 0 kg CO_2-e/kWh and has no contribution

Annual GHG emissions from electricity (state grid) consumption:

$$Y = Q \times EF \times 10^{-3}$$

Where:

Y = Scope 2 emissions (t CO_2-e)

Q = quantity of electricity purchased (kWh). If the electricity purchased is measured in gigajoules, divide the amount of gigajoules by 0.0036 to determine the quantity of kilowatt hours.

EF = is the Scope 2 emission factor, for the State, Territory or electricity grid in which consumption occurs (kg CO_2-e per kilowatt hour)

to emissions.

Table 19. Scope 2 and 3 emission factors for the consumption of purchased electricity. Adapted from Commonwealth of Australia (2019)

State or Territory	**Scope 2 Emission factor** kg CO_2-e/kWh	**Scope 3 Emission factor** kg CO_2-e/kWh	**Full carbon footprint (Scope 1, 2, 3)** kg CO_2-e/kWh
New South Wales and Australian Capital Territory	0.81	0.09	0.9
Victoria	1.02	0.10	1.12
Queensland	0.81	0.12	0.93
South Australia	0.44	0.10	0.54
South West Interconnected System (SWIS) in Western Australia	0.69	0.04	0.73
North Western Interconnected System (NWIS) in Western Australia	0.59	-	-
Darwin Katherine Interconnected System (DKIS) in the Northern Territory	0.55	-	-
Tasmania	0.15	0.02	0.17
Northern Territory	0.63	0.08	0.71
Australia	0.73	0.09	0.82

Adapted from Commonwealth of Australia (2019)

Example

A feedlot in QLD consumes 200 000 kWh of purchased electricity from the grid.

Scope 2 emissions in tonnes of CO_2-e are estimated as follows:

$$Y = 200\ 000 \times 0.81 = 162\ 000 \text{ kg } CO_2\text{-e}$$

9.4.3 Emissions estimation methods - feed, fertilisers, energy, transportation (Scope 3 emissions)

Emissions from common farm inputs are provided in kg CO_2-e per unit (Table 20).

Table 20. Scope 3 emissions from common farm inputs, analysed using GWP_{100}, AR5 (IPCC 2015)

Input	Emissions intensity (*kg CO_2-e/t*)	Data Source	Economic allocation
Barley grain, Northern regions	269	Average yield between 2011-2016 (AusLCI 2020)	100%
Barley grain, Central regions	341	Average yield between 2011-2016 (AusLCI 2020)	100%
Barley grain, Southern regions	229	Average yield between 2011-2016 (AusLCI 2020)	100%
Barley grain, Western regions (WA)	290	Average yield between 2011-2016 (AusLCI 2020)	100%
Sorghum grain, Average Australia	242	Average yield between 2011-2016 (AusLCI 2020)	100%
Wheat grain, Northern regions	156	Average yield between 2011-2016 (AusLCI 2020)	98%
Wheat grain, Central regions	252	Average yield between 2011-2016 (AusLCI 2020)	98%
Wheat grain, Southern regions	164	Average yield between 2011-2016 (AusLCI 2020)	98%
Wheat grain, Western regions (WA)	206	Average yield between 2011-2016 (AusLCI 2020)	98%
Maize grain, Northern regions	164	Average yield between 2011-2016 (AusLCI 2020)	100%
Maize grain, Central regions	212	Average yield between 2011-2016 (AusLCI 2020)	100%
Maize grain, Southern regions	124	Average yield between 2011-2016 (AusLCI 2020)	100%
Straw from wheat	67	Economic allocation 34.9% based on average price of wheat straw at 108$/tonne and grain at $288/tonne between 2015-2019. Average yield was based on 5 year average from 2014-2018 (ABS 2016, 2017, 2018, 2019).	2.0%
Cereal hay and silage at farm	193	Average yield between 2011-2016 (AusLCI 2020)	-
Cottonseed meal	111	Economic allocation 33.8% based on average price of $276/tonne (AusLCI 2020)	33.8%
Cottonseed (whole seed)	208	Average yield between 2014-2018 (ABS 2016, 2017, 2018, 2019); Economic allocation 14% based on average price of $343/tonne and $548/bale between 2014-2018.	14%
Cotton hulls	11	IAE estimated base on yield in 2015	-
Canola meal at oil mill	284	Economic allocation 29.5% based on average price of $276/tonne for 5 years 2008-2012 (AusLCI 2020)	29.5%
Canola oil at oil mill	1096	Economic allocation 70.5% based in average price of $1066/tonne for 5 years period between 2008-2012 (AusLCI 2020)	70.5%
Molasses from sugar at mill	52	Economic allocation 2.4% based on price of $50/tonne and $400/tonne sugar (AusLCI 2020)	2.4%
Feedlot dry supplement	1345	(Wiedemann *et al.* 2017)	100%
Feedlot wet supplement	213	(Wiedemann *et al.* 2017)	100%
B-Double, 38 tonne load on 30t truck	0.05*	(AusLCI 2020)	100%

** kg CO_2-e/tkm*

9.4.4 Emissions estimation methods - feeder cattle

Feedlot cattle spend 80 – 90% of their lives grazing before entering the feedlot. Hence, feeder cattle emissions represent most of the full carbon footprint of the feedlot, and these emissions need to be accounted for. In a verified carbon footprint for a market claim, it would be necessary to collect some activity data related to feeder cattle for your feedlot (see Appendix 9.1 on data quality). However, for indicative purposes, emissions from feeder cattle can be estimated using default regional values (Table 21).

Table 21. Example default emission factors for purchased feeder cattle emissions based on (Wiedemann, Henry, McGahan, Grant, *et al.* 2015; Wiedemann, McGahan, Murphy, and Yan 2015)

Origin of cattle	Emissions Factor*
North QLD	12.4
South/central QLD	12.4
North NSW	11.7
South NSW/VIC/South SA	11.7
NSW/SA pastoral zone	12.4
South-west WA	11.7
WA pastoral zone	12.4

*Adjusted to AR5 GWP_{100}