Dairy Australia

UNIVERSITY of TASMANIA
TIA
Tasmanian Institute of Agriculture

Australian Dairy Carbon Calculator Manual

Version 6.1

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Acknowledgements

Dairy Australia and the Tasmanian Institute of Agriculture (TIA) would like to acknowledge and give thanks to Meat & Livestock Australia and Integrity Ag & Environment for the use of background text (e.g. information on GHG emissions, emission sources etc) from their carbon accounting technical manual for the Sheep Beef Greenhouse gas Accounting Framework (SB-GAF) calculator.

We would also like to thank Agriculture Victoria for allowing the reproduction of Figure 1 (adapted with updated GWPs for this manual).

The original Australian Dairy Carbon Calculator (ADCC), previously known as the Dairy Greenhouse gas Abatement Strategies (DGAS) calculator, was developed in the late 2000's with funding from Dairy Australia and the Australian Government Department of Agriculture, Fisheries and Forestry.

Over time, the calculator has been maintained and upgraded within projects funded by the Australian Federal Government Department of Agriculture, Fisheries and Forestry, Dairy Australia, Meat & Livestock Australia, and Australian Wool Innovation. Version 5 of ADCC was funded by Dairy Australia. We acknowledge funding from all above-mentioned agencies to allow the development and upgrading of the calculator as required to meet the most current guidelines.

Many thanks to the Agriculture Victoria team for providing access to the Dairy Farm Monitor Project and Queensland Dairy Accounting Scheme datasets. This allowed us to review 2,141 dairy farm datasets to benchmark GHG emissions.

We have now incorporated a method of importing a DairyBase farm system file into ADCC to allow further exploration of mitigation options. Version 6.1 now has a fresh look, with clearer lines and altered functions such as using Notes as opposed to pop-up comments. Thank you to Richard Morris for building this new functionality and providing on-going support as required.

Lastly, a huge thank you to everyone who made suggestions to improve ADCC and/or took the time to review this manual.

Citation:

KM Christie-Whitehead and Dairy Australia (2025) Australian Dairy Carbon Calculator (ADCC). (Tasmanian Institute of Agriculture: Launceston, Tasmania; Dairy Australia: Melbourne, Victoria).

Table of Contents

1. Australian Dairy Carbon Calculator Manual

The Australian Dairy Carbon Calculator manual contains five theme areas:

- Carbon accounting (sections 1-4),
- Australian Dairy Carbon Calculator (section 5),
- Benchmarking of DairyBase datasets (section 6),
- Profitable Emissions Action Plan (section 7), and
- GHG adaptation options explored in the Carbon Offset Scenario Tool (section 8)

This version of the manual contains all sections. We have also separated each of these theme areas into four separate stand-alone documents. These can be downloaded from the Dairy Australia website if users wish to focus on one or two components of the overall manual.

The Australian Dairy Carbon Calculator (ADCC), and its predecessor the Dairy Greenhouse gas Abatement Strategies (DGAS) calculator, has been developed by the Tasmanian Institute of Agriculture (TIA). The calculator is based on the most current estimations of national greenhouse gas (GHG) emissions as reported in the National Greenhouse Gas Inventory (NGGI; https://www.dcceew.gov.au/climate-change/publications/national-inventory-reports).

The calculator is intended to give the user an understanding of the net GHG emissions emitted from their business, both in absolute terms and emissions intensity (EI). The gases, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are multiplied by the current global warming potential (GWPs), as reported in NGGI. The Australian NGGI methodology has amended the global warming potentials (GWP_{100}) for methane (CH_4) and nitrous oxide (N_2O) to align with the 2014 IPCC Fifth Assessment Report (AR5) values of 28 and 265, respectively. Currently, there is an IPCC Assessment Report released (AR6) which now separates CH_4 derived from fossil fuels (e.g. associated with fuel consumption) from that derived from non-fossil fuels (e.g. enteric fermentation and waste). The new AR6 GWP_{100} values are 30 and 27 for fossil and non-fossil derived CH_4, respectively, and 273 for N_2O emissions. However, as these AR6 values have not yet been incorporated into NGGI, the ADCC tool remains using the AR5 values of 28 and 265 for CH_4 and N_2O, respectively.

The ADCC also allows the user to explore a range of potential abatement options to reduce on-farm GHG emissions. Options fall into four theme areas:

1. Diet manipulation to reduce enteric CH_4 and N_2O. Examples could include feeding a supplement high in dietary fat or improving the energy to protein ratio of the diet,
2. Herd and breeding management to reduce enteric CH_4 emissions. Examples could include breeding animals with a lower CH_4 production per kg of dry matter intake (DMI), inclusion of CH_4 inhibitors (e.g. 3-nitrooxypropanol) or extended lactations to reduce the number of replacement animals required,
3. Feedbase management to reduce N_2O emissions. Examples could include the use of a nitrification inhibitor to reduce N_2O emissions from urine patches, and
4. Abatement strategy farm where one or more aspects of the 'Your Farm' tab can be altered to reduce CH_4 and/or N_2O emissions. Examples could include the introduction of tree vegetation to sequester carbon, reduced herd replacement rate to lower emissions from non-lactating young stock or an alteration of the amount of N fertiliser applied to land.

2. Glossary and commonly used acronyms

3-NOP	3-nitrooxypropanol trading as Bovaer®
Abatement	Strategy to reduce net GHG emissions
ACCU Scheme	The Australian Carbon Credit Unit (ACCU) Scheme, formerly known as the CFI, ERF and CSF
ADCC	Australian Dairy Carbon Calculator
Allocation	Dairy farms produce milk and meat. ADCC allocates net GHG emissions, based on an energy allocation method, to milk and meat
Anthropogenic	GHG emissions caused or influenced by people, either directly or indirectly
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
Benchmarking	Comparing the performance of the enterprise against the rest of the industry
Carbon accounting	The process used to qualify greenhouse gas (GHG) emissions of an enterprise
Carbon flux	The change in carbon stocks stored in sinks over a duration, usually a yearly basis
Carbon footprint	Quantification of the GHG emissions emitted directly or indirectly by an individual, company, or product
Carbon negative/carbon positive	Condition in which net carbon dioxide equivalent emissions are negative and positive, respectively. However, these terms can be ambiguous and are sometimes used inconsistently. Therefore, the dairy industry is moving away from the use of these terms and referring to a farm as remaining either an emitter of emissions (i.e. has not attained carbon neutrality/net zero), as net zero (all emissions offset by carbon sequestration), or a beyond net zero (sequestering more carbon than emitting)
Carbon neutrality	Net-zero GHG emissions
Carbon sequestration	The process whereby carbon dioxide is removed from the atmosphere and stored in carbon sinks such as soils and vegetation
Carbon sink	A reservoir that absorbs carbon dioxide from the atmosphere. Natural carbon sinks include plants, soils, and oceans
Carbon stocks	Carbon stocks refers to the quantity of carbon that has been sequestered from the atmosphere and is stored in a carbon sink
CFI	Carbon Farming Initiative; the original Federal government voluntary carbon credit scheme, later replaced with the ERF and subsequently the CSF
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents (CO_2e) are a unit used to compare emissions from different GHGs based on their global warming potential (GWP) over a specific timeframe, typically 100 years (GWP_{100})
COST	Carbon Offset Scenario Tool, a series of mitigation options embedded within ADCC
CP	Crude protein
CSF	Climate Solutions Fund; the Australian Government's previous voluntary carbon credit scheme, formerly known as the CFI and subsequently the ERF. Now called the ACCU scheme.
DFMP	Dairy Farm Monitor Project
DGAS	Dairy Greenhouse gas Abatement Strategies calculator, the original name for ADCC
Direct N_2O	Nitrous oxide lost to the environment from deposition of urine, dung, effluent, and nitrogen-based fertilisers (see indirect N_2O)
DM	Weight of feed after all moisture is removed
DMD	Dry matter digestibility

DMI	Dry matter intake is the amount of moisture-free feed an animal consumes, usually referred to on a daily basis
EF	Emission factor
Emissions intensity	Emissions intensity (EI) is a metric based on the net GHG emissions relative to the output (e.g. kg of fat and protein corrected milk or kg liveweight). EIs allow for comparison and benchmarking between farms of varied sizes and production levels
Energy allocation	ADCC allocated GHG emissions based on the total energy attributed to milk production versus meat production
Enteric methane	Enteric methane is produced through enteric fermentation when plant material is broken down in the rumen and is a by-product of this digestive process. Methane is released primarily through belching and exhalation
ERF	Emissions Reduction Fund is the Australian Government's second voluntary carbon credit scheme, formerly known as the CFI and then later replaced with the CSF and subsequently the ACCU scheme
FPCM	Fat and protein-corrected milk is a kg of milk standardised to 4.0% fat and 3.3% protein to allow comparison of milk with varying fat and protein percentages
GHGs	Greenhouse gases are gases that absorb and emit radiant energy. The main GHGs associated with agriculture are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)
Global temperature potential	Global Temperature Potential (GTP) is an alternative to GWP_{100} to report the warming potential of methane, based on the change in global mean surface temperature, usually on a yearly time-step
Global warming potential	Global warming potential (GWP) is a measure of cumulative radiative forcing, which aims to quantify the long-term contribution of a GHG to global warming. Each GHG has a specific GWP value, and this is relative to a specific timeframe
GWP_{100}	Global warming potential based on a 100-year time horizon
IPCC	Intergovernmental Panel on Climate Change, established in 1988 to provide scientific information on anthropogenic climate change, including the impacts, risks, and possible response options
Indirect N_2O	A proportion of the nitrogen applied to soils via animal urine, dung, and effluent, or as nitrogen-based fertilisers, can be lost to the environment as volatilised ammonia or leaching/runoff nitrate. Over time, this nitrogen is redeposited onto soils in rainfall (volatilised N) or deposited into water courses (leached/runoff N). A proportion of this redeposited nitrogen will be transformed into nitrous oxide through the processes of nitrification and denitrification
K	Potassium
LW	Liveweight of an animal, usually reported as kgs
LWG	Liveweight gain of an animal, usually reported as kg/day
Manure	Manure is used in this manual when referring to the sum of urine and dung. At times, waste is also used as an alternative term for manure. Unless stipulated, manure refers to the sum of urine and dung deposition
Manure management system	Manure management system (MMS) refers to the method of handling animal manure. MMSs for dairy include directly voided onto pastures during grazing, pond/lagoons, sump/dispersal, drains to paddock daily, and solid storage
ME	Metabolisable energy, with units of megajoules (MJ) per kg dry matter intake
Methane	Methane (CH_4) is a GHG that is 28 times more potent than carbon dioxide over a 100-year timeframe, based on the IPCC AR5 report. Methane is released to the environment via the digestion process (enteric CH_4) and with manure management (waste CH_4)
Methane conversion factor	Methane conversion factor (MCF) defines the proportion of methane-producing potential of each manure management system. Pond/lagoons have a higher MCF than other storage systems
MJ	Megajoules
N	Nitrogen

Net emissions	Total GHG emissions minus carbon sequestered in carbon sinks (trees and/or soils)
NGGI	The National Greenhouse Gas Inventory accounts for, and estimates, Australia's GHG emissions and sinks
NGER	National Greenhouse and Energy Reporting
NH_4	Ammonium
Nitrous oxide	Nitrous oxide (N_2O) is a GHG that is 265 times more potent than carbon dioxide, based on the IPCC AR5 report. N_2O is released to the environment when micro-organisms in the soil act on the nitrogen applied to the soil, whether that N is deposited via animal urine, dung, effluent, or nitrogen-based fertilisers
N_2O	Nitrous oxide
NO_3	Nitrate
P	Phosphorus
Pre-farm embedded emissions	GHG emissions associated with the production/manufacturing of key farm inputs such as grain, fodder, and fertiliser. In ADCC, pre-farm embedded emissions do not include the emissions associated with the transportation of these inputs from the point of production to the farm gate, due to the difficulty in establishing distances travelled for grain, fodder, and/or fertilisers
S	Sulphur
SAR	IPCC Second Assessment Report
Scope	Standard practice is to report GHG emissions using different classifications depending on where they arise from, and how they relate to the business. These are termed emission 'scopes'
Scope 1 emissions	Direct GHG emissions from sources that are owned or controlled by the business. For dairy farms, this refers to emissions from on-farm methane and nitrous oxide, along with carbon dioxide emissions from the consumption of fuel
Scope 2 emissions	GHG emissions from the generation of purchased electricity consumed by the business
Scope 3 emissions	GHG emissions that are a consequence of the activities of the business, but that occur from sources not owned or controlled by the business. For dairy farms, these are GHG emissions from the production of key farm inputs (i.e. pre-farm embedded emissions), extraction/refinement of fuel, and indirect loss of electricity through transmission and distribution in the grid
Waste	Waste is used in this manual when referring to the sum of urine and dung. At times, manure is used as an alternative term for waste. Unless stipulated, waste means the sum of urine and dung deposition

3. Introduction

There is no doubt that human-induced climate change is occurring, and that greenhouse gases (GHGs) are contributing to this global warming. Many companies, governments, and industries have either established or are establishing targets to reduce GHG emissions, with many targeting carbon neutrality or net-zero emissions by 2050. The current Australian Federal government has set a target of 43% reduction of GHG emissions by 2030, and net zero by 2050, relative to the 2005 baseline (https://www.dcceew.gov.au/about/news/australia-submits-new-emissions-target-to-unfccc). Australian agriculture is facing increased consumer and community pressure to reduce emissions, while maintaining /improving productivity to remain profitable. The Australian dairy industry set a target of reducing GHG emissions intensity (EI) by 30% across whole of industry (farm and manufacturing) by 2030[1] as part of the Dairy Industry Sustainability Framework (Dairy Australia, 2021).

The cost of direct measurement of on-farm GHG emissions is expensive, time-consuming, and requires specialised equipment. Annual GHG emissions generated by dairy production, and other farm-related operations critical to the success of dairying, can be estimated by undertaking a 'carbon account'. Accounting allows producers to ascertain their current farm GHG emissions. It can also help them identify hot-spots within the farm boundary so they can better understand how to reduce their carbon footprint.

Greenhouse gases represent lost 'energy' from the farm system. For example, reducing enteric CH_4 has the potential to retain this energy within the animal, which may result in an increase in milk production and/or liveweight gain. Likewise, excess applications of N fertiliser, beyond that required by pastures, can potentially be lost to the environment through leaching, volatilisation, and N_2O emissions. Reducing GHGs can yield a range of other benefits both within and beyond the farm gate, such as:

- increased productivity and long-term sustainability
- improved social licence to farm
- improved access to emerging markets for low carbon/net zero products

The Australian dairy industry is committed to reducing its carbon footprint, and tools such as ADCC are critical to help producers firstly ascertain their baseline GHG emissions, and secondly, determine areas of improvement that can be undertaken on farm. This manual provides guidance in the use of the ADCC, including detailed information on how to complete a carbon account for dairy production, and highlights opportunities for reducing GHG emissions through a range of abatement strategies (COST within ADCC). This manual also included benchmarking results from the Dairy Farm Monitor Project datasets within DairyBase. The Dairy Australia website https://www.dairyaustralia.com.au/climate-and-environment contains several sections to help farmers manage their land, water, and climate to improve farm production and profitability. Good farm management practices will generally result in a reduction in GHG emissions per unit of milk and meat production. However, it is critical that farmers also explore aspects of the farm business that can be improved, to directly reduce net farm GHG emissions.

[1] 2015-16 baseline year

4. Carbon accounting

4.1. Major greenhouse gases

Greenhouse gases reported under the Australian Federal Government's *National Greenhouse Gas Inventory* (commonly referred to as NGGI; Australian Government, 2022) include:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- sulphur hexafluoride (SF_6)
- other hydrofluorocarbons and perfluorocarbons

The main emissions from agricultural production are CO_2, CH_4 and N_2O (Figure 1; reproduced with modifications courtesy of Agriculture Victoria). Greenhouse gas emissions are measured in CO_2 equivalents (CO_2e) to allow for comparison in terms of the potency of each gas, as each has a different capacity to contribute to global warming. Methane has a potency, or global warming potential (GWP), of 28 times that of CO_2, when reported on a 100-year timeframe (GWP_{100}). In contrast, N_2O has a GWP_{100} of 265 times that of CO_2. The most recent 2023 IPCC Sixth Assessment Report (AR6) now separates CH_4 derived from fossil and non-fossil sources. As such, there are differing GWPs for each, at 30 and 27, respectively. In addition, the GWP for N_2O has altered to 273. However, since the NGGI methodology has not made the change to their GWPs, we have maintained the AR5 values within ADCC.

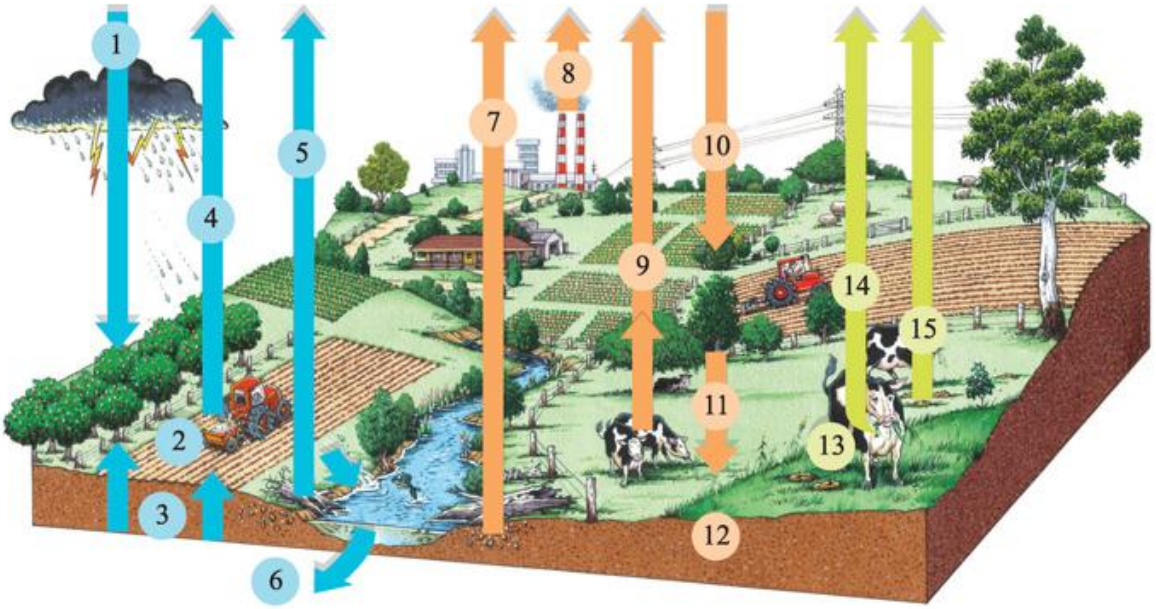
It is well recognised that limitations may exist to the GWP_{100} method, particularly around how CH_4 is managed (IPCC 2014; Lynch *et al*. 2020). Methane breaks down into biogenic CO_2 and water vapour after around 10–14 years. The warming effect of CH_4 during these years is significantly higher, at around 80+ times more potent than CO_2 over the shorter timeframe. Accounting for the warming effect over a much longer period (100 years) may be problematic if this breakdown factor is not accounted for. Several other metrics have been proposed including Global Temperature Potential (GTP; IPCC 2014) and GWP* (Lynch *et al*. 2020), and these report lower impacts for CH_4 under specific scenarios.

In the future, new methods, such as GTP and GWP*, may gain more traction and become standard international practice. We note that these GWP_{100} values are periodically updated in response to new science, and for the purposes of ADCC and this manual, the AR5 GWP_{100} values of 28 and 265 for CH_4 and N_2O have been applied to remain aligned with the Australian Government inventory, as of July 2025.

Nitrous oxide
is mainly released through applications of nitrogen fertilisers, urine and dung to soils and through soil disturbance. The global warming potential of nitrous oxide is 265 times that of carbon dioxide over a 100 year period.

Carbon dioxide
is mainly released through the burning of fossil fuels to generate electricity and the consumption of fuel on farm. It is absorbed by plants through photosynthesis and can be stored in trees and soils.

Methane
is mainly released as a by-product of the digestible process. A smaller amount is released from manure under anaerobic conditions. The global warming potential of methane is 28 times that of carbon dioxide over 100 year period.



1 Nitrogen fixed by lightning (falls in rain) and nitrogen fixing bacteria in legumes

2 Nitrogen-based fertilisers applied to pasture or crops

3 Nitrogen taken up by pasture, crops and trees

4 Nitrous oxide released through volatilisation of urea fertiliser

5 Nitrous oxide released through process of denitrification

6 Nitrogen loss through runoff and leaching from fertilisers and nitrification process in soil

7 Carbon dioxide released through plant decay, and insect and microbial activity in the soil

8 Carbon dioxide released from burning fossil fuels to produce electricity and fuel

9 Carbon dioxide released by animals and plants through respiration

10 Carbon absorbed by trees, pasture and crops through photosynthesis

11 Animals consume carbon by eating plants

12 Carbon from organic residues (e.g. dead leaves, roots, manure & urine) absorbed into the soil

13 Methane (CH_4) is produced within the rumen (fore-stomach) during digestion, via a chemical reaction between carbon and hydrogen

14 Methane released by cows and sheep burping following ruminant digestion

15 Small amounts of methane released from fermentation of animal dung and urine under anaerobic (no oxygen) conditions

Figure 1. Sources of major dairy farm greenhouse gas emissions (Courtesy of Agriculture Victoria (2022), adapted with updated GWPs).

4.2. Methane

Enteric CH_4 is a by-product of ruminant digestion and mainly occurs in the rumen, and to a lesser extent, the large intestine. Cellulose and starches are broken down into volatile fatty acids through microbial activity (methanogenic bacteria), releasing hydrogen, which combines with CO_2 to form CH_4. Enteric CH_4 results in the loss of 5-10% of gross energy intake, energy that could otherwise be used to increase productivity (e.g. increase milk production for cows or increase daily liveweight gain for young stock). The Australian NGGI methodology estimates enteric CH_4 production as 20.7 g CH_4/kg dry matter intake (DMI; Charmley *et al*. 2016), equivalent to ~ 3.8 t CO_2e/annum, assuming each cow eats 20 kg DM/day while lactating, and 8 kg DM/day while dry.

Methane is also lost to the environment from waste/manure (dung and urine deposition) when stored in anaerobic (absence of oxygen) conditions, such as lagoon/pond systems. Waste CH_4 emissions in Australia are generally relatively low as most dung and urine are deposited onto pastures as animals are grazing. Exceptions to this is with housed systems, similar to that found in Europe and North America. ADCC uses state-based data to ascertain what proportion of waste is managed via five manure management systems (MMS). These are:

- deposited onto pasture while grazing,
- anaerobic pond/lagoon system,
- sump dispersal system,
- drains/spread to the paddock daily, and
- solid storage.

The default in ADCC is that between ~ 80 and 85% of the milking herds' waste is deposited onto pastures (proportion varies between states). The remaining ~ 15-20% is deposited at the dairy shed. This residual waste is then divided between the four remaining manure management systems, with the proportion of manure to each system varying between states. Each manure management system has a varying methane conversion factor (MCF), with the risk of CH_4 loss from pond/lagoon systems substantially greater than all other systems. With the dairy industry increasingly relying on feedpads to deliver partial or total mixed rations to the milking herd, ADCC also allows users to explore how their farm's waste is managed under these feeding regimes, to give a more accurate reflection of waste CH_4 emissions.

4.3. Nitrous oxide

Nitrous oxide emissions arise from waste excretion (urine and dung) and nitrogen (N)-based fertiliser applications (e.g. urea, diammonium phosphate (DAP), sulphate of ammonia (SoA)). Emissions of N_2O are largely a result of two soil microbial processes, nitrification, and denitrification. Nitrification is an aerobic process that oxidises ammonium (NH_4^+) to nitrate (NO_3^-), with denitrification of N_2O produced as a by-product. Denitrification is also an anaerobic process that reduces nitrate into dinitrogen (N_2), with N_2O an obligatory intermediate (de Klein and Eckard, 2008). A simplified N cycle of a grazed dairy pasture is shown in Figure 2, illustrating the points in the N cycle where nitrification and denitrification occurs.

Factors that significantly affect the production of N_2O from animal waste and fertilisers are temperature, water-filled pore space (WFPS), level of organic carbon, soil pH, and soil NO_3 (Whitehead 1995). Soil NO_3 levels and soil aeration (WFPS) have been identified as the most likely key factors affecting N_2O emissions from grazing systems (Eckard *et al*. 2010). In addition to direct losses of N_2O as described above, a proportion of N lost to the environment through leaching and/or runoff of NO_3 and ammonia (NH_3) volatilisation. When these sources of N are redeposited on land, the N cycle begins again, resulting in a proportion of this N lost as indirect N_2O emissions.

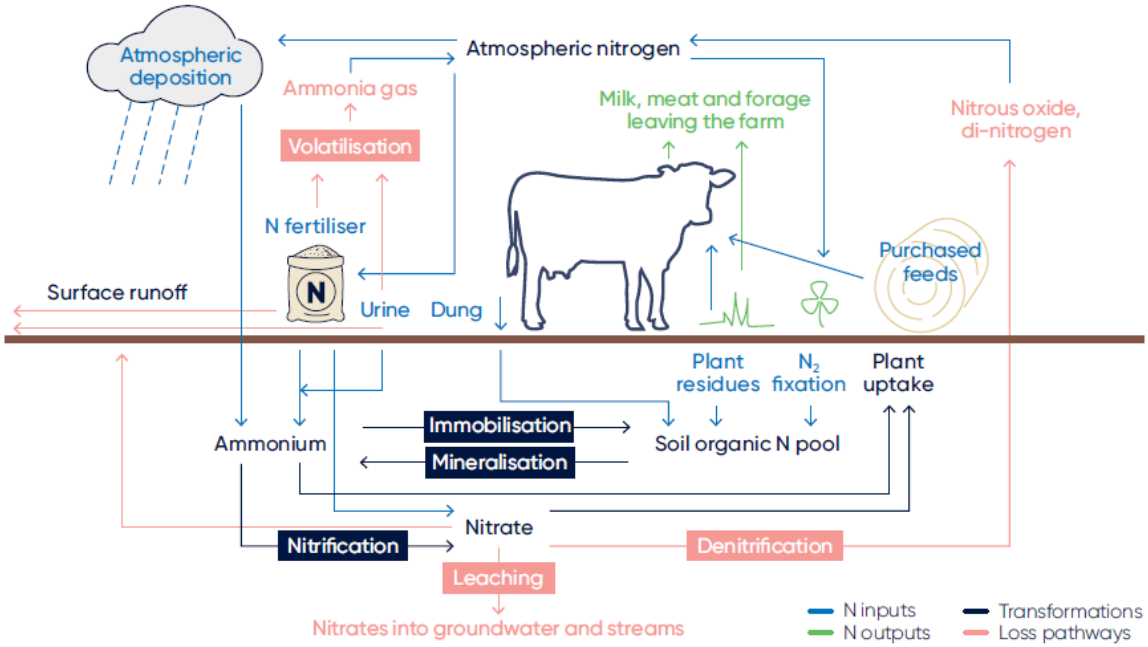


Figure 2. Simplified nitrogen cycle of a grazed dairy pasture (Source: Dairy Australia 2020: Fert$mart Nitrogen Pocket Guide).

4.4. Carbon dioxide

Carbon dioxide emissions on dairy farms come from a range of sources. These include burning fossil fuels for electricity sourced from the grid, and fuel for farm vehicles and equipment. Urea manufacturing removes CO_2 from the atmosphere. When applied to pastures and crops, this CO_2 is released back into the atmosphere. Lime undergoes a similar process as urea, releasing CO_2 to the atmosphere when applied to pastures and crops. Carbon dioxide emissions (mainly CO_2 but also smaller amounts of CH_4 and/or N_2O) arise from the manufacturing and transporting of key farm inputs, such as fertilisers and feeds. Soils also respire CO_2 as organic matter (pastures, roots etc) breaks down. Carbon dioxide is also sequestered (stored) in soils through building soil organic matter and in the growth of vegetation, such as trees and shrubs. The CO_2 from on-farm electricity and diesel consumption, the production/manufacturing of supplementary feeds and fertiliser, and the breakdown of urea and lime are all estimated in ADCC. The emissions associated with the transportation of key farm inputs are not included. This is due to large variation in the distances that key inputs may need to travel from the point of production or manufacturing to the farm gate. ADCC also does not estimate soil net CO_2 respiration. However, users can decide if they wish to estimate soil/tree carbon sequestration to offset a proportion of their GHG emissions.

4.5. Carbon accounting and carbon footprinting

Measuring GHG emissions on farm is time-consuming, complex, and expensive. As such, GHG emissions are often modelled using well-validated equations from the most current scientific research relevant to a region. These finding are then incorporated into methodologies (i.e. NGGI) to estimate GHG emissions and carbon sequestration. An example of this is the equation to estimate enteric CH_4, based on the research of Charmley *et al*. (2016). Their meta-analysis study reviewed research trials undertaken throughout Australia that used open-circuit respiration chambers to measure enteric CH_4 emissions. For example, Agriculture Victoria's Ellinbank dairy research facility is considered the 'Gold-Star' for measuring enteric CH_4 emissions. Any results from diets that were considered to inhibit the reduction in enteric CH_4 (e.g. high in dietary fat or tannins) were omitted from the meta-analysis. This resulted in > 1,000 datapoints to develop the NGGI relationship between intake and CH_4 production, at 20.7 g CH_4/kg DMI (Charmley *et al*. 2016).

A **carbon account** represents the net GHG emissions (i.e. total GHG emissions minus carbon sequestration) and is generally reported on an annual timeframe, as t CO_2e/annum. While useful, a carbon account does not allow for comparison between different farm sizes or production levels.

A **carbon footprint**, commonly known as emissions intensity or EI, represents the net GHG emissions per unit of product over 12 months, such as kg CO_2e per kg milksolids (MS) or kg CO_2e per kg of fat and protein-corrected milk (FPCM). Most milk EIs use an equation to standardise milk production based on fat and protein content. The ADCC tool uses FPCM, based on the International Dairy Federation guidelines of standardising milk to 4.0% fat and 3.3% protein (IDF, 2022). In addition, EI is also estimated in ADCC by dividing net GHG emissions by kg of milksolids. EI allows the comparison of a farm's GHG emissions over time, accounting for changes in production, herd size etc. Alternatively, EI's enables the comparison of a farm's GHG emissions with other farms within the region, other regions of Australia, or even globally[2].

Dairy farms produce several products, not just milk, but also meat with cull cows, non-replacement heifers, and bull calves/steers. The dairy industry is increasingly retaining more calves on farm, especially bull calves. Thus, it is important that **allocation** of net GHG emissions is attributed to both milk and meat production. There are a range of allocation methods available (e.g. economics, protein, systems expansion; Flysjö *et al*. (2011); Kyttä *et al.* (2022)). In ADCC, we use an energy allocation method where net emissions are attributed to both milk and meat based on the known relationships between net energy requirements for lactation and growth, and the production of milk and meat (IDF, 2022 following Thoma and Nemecek (2020)). See Appendix 1 for a complete explanation of how GHG emissions are allocated to milk vs meat).

When comparing results between farms, it is also important to understand the allocation method used, as EI will alter between methods. For example, Flysjö *et al*. (2011) found that the EI for a New Zealand case study farm was 1.00 kg CO_2e/kg energy-corrected milk when 100% of emissions were allocated to milk. However, EI could be as low as 0.63 CO_2e/kg energy-corrected milk when using a systems expansion GHG allocation.

[2] Assuming same GWPs and standardisation of milk production

When estimating a carbon account or footprint, it is important to also define the **system boundary**. In most instances, the system boundary encompasses all GHG emissions arising within the operational and organisational boundary of the farm enterprise. Therefore, this includes on-farm emissions associated with milk production (e.g. enteric CH_4 emissions from livestock), feed production (e.g. N_2O emissions from fertiliser inputs), and manure management (e.g. CH_4 and N_2O emissions from dung and urine). It also includes emissions associated with key inputs, commonly known as pre-farm embed emissions. These include supplementary feed, and manufactured fertilisers. In addition, emissions associated with off-farm generated electricity and diesel are included. Dairy farms may agist their replacement heifers, and sometimes even dry cows, with another farm business (i.e. we are not referring to a runoff/outblock here but a separate farm that the current farm owner has no control over). It is important to note that even though these animals are not within the physical boundary of the farm, they are part of the operational boundary of the dairy farm enterprise. Therefore, these animals must be included in the carbon account.

In most instances, the carbon account or footprint often concludes at the farm gate, commonly termed 'cradle to gate'. The reason is that, at this point, the farmer no longer has control of the milk they produce. Emissions associated with transporting raw milk for processing, milk processing, delivering of product(s) to the consumer, and wastage at the consumer level is beyond the farmer's control. Studies such as Life Cycle Assessments (LCAs) include both on-farm emissions and those emissions through the supply chain, from processing through to the consumer (termed cradle to grave).

4.6. Scope emissions breakdown

Greenhouse gas emissions are often defined according to where and when they occur. Direct GHG emissions are those from sources owned or controlled by the farmer. Indirect GHG emissions are those that are a consequence of the activities of the farm but occur at sources owned or controlled by another business (Note we are not referring to indirect N_2O emissions here, which are Scope 1 emissions). Ranganathan *et al.* (2004) developed three scopes to help delineate direct and indirect GHG emissions:

Scope 1 GHG emissions are direct emissions under the control of the farmer, such as enteric and waste CH_4 emissions, N_2O emissions from animal waste and N-based fertilisers, CO_2 emissions from lime and urea applications on farm, as well as CO_2 emissions from the consumption of fuel in farm vehicles and machinery.

Scope 2 GHG emissions are the CO_2 emissions associated with the generation of purchased electricity consumed on farm. These are also considered direct emissions as a farmer could reduce their electricity consumption, or install renewable energy on farm, to reduce consumption of fossil-derived electricity.

Scope 3 GHG emissions are indirect emissions when they are associated with the farm but occur off-farm. These include the CO_2e emissions associated with the production of key-farm inputs, such as grain and fodder, fertilisers, and soil ameliorants (lime). Scope 3 also includes emissions associated with the extraction and manufacturing of fuel, in addition to the indirect loss of electricity during transmission and distribution in the power grid. For example, a dairy farmer has no direct control over the management decisions of a cropping farm, e.g. N fertiliser inputs. But they can make the decision as to whether to buy from a farm that can illustrate that their grain's EI is lower than that of a neighbouring farm, due to lower N fertiliser inputs.

A carbon footprint requires all three Scope emissions to be included and is frequently required for Carbon Neutral certification under systems such as the Federal Government's *Climate Active* program (www.climateactive.org.au).

Carbon Neutral: The GHG emissions from a business, industry or nation are equally balanced by an stored/sequestered carbon and/or purchased offsets. Therefore, the balance of emissions sources to sinks or offsets is equal. In some cases, entities refer to carbon neutrality when accounting for only CO_2 emissions being balanced with CO_2 sequestration; i.e. carbon neutrality ignores source of other non-CO_2 gases such as CH_4 and N_2O being included with CO_2 as source emissions.

Net Zero: The GHG emissions from a business, industry or nation are equally balanced by any stored/sequestered carbon. Direct and within supply chain emissions reduction activities are prioritised over purchased offsets

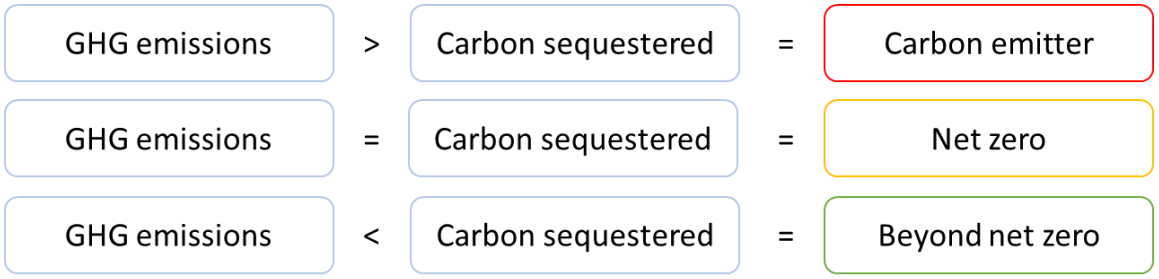


Figure 3. A farm remains a carbon emitter (red outcome) when GHG emissions are greater than carbon sequestered. A farm is Net Zero (orange outcome) when the amount of carbon sequestered is equal to GHG emissions. The best outcome is when the amount of carbon sequestered is greater than GHGs emitted as the farm is now beyond Net Zero (green outcome).

4.7. Commonly asked questions

While not extensive, here are some commonly asked questions related to undertaking assessments of dairy GHG emissions.

Why do you count feed inputs, such as grain and fertiliser inputs, as part of the dairy farm's carbon footprint? Is this not double counting the emissions?

When the Australian government estimates national GHG emissions each year, the emissions from dairy supplementary feeds such as grain and fodder is only counted once, on the farm where it is produced. The emissions associated with urea production is attributed to the country where the urea is manufactured.

However, when we scale GHG estimations down to the farm-scale, it should be noted that the GHG emissions attributed to the dairy farm is the sum of direct emissions, those from sources owned or controlled by the farmer (Scope 1 and 2), and indirect emissions, those as a consequence of the activities of the farm but occur at sources owned or controlled by another business (Scope 3).

Farmers can make a choice to feed less grain and rely more on home-grown pastures and forages. Similarly, farmers can choose to increase the legume content of their pasture as opposed to applying N fertiliser to increase pasture production. Either option would reduce their Scope 3 GHG emissions and thus their net GHG emissions.

Why do I not get credited for the carbon I sequester in pastures and crops?

If the carbon sequestered in pastures and crops was permanently stored, farmers could be credited for the carbon stored in these feeds. However, pastures and crops are either grazed directly, or conserved and fed out to livestock at a later stage. Thus, a proportion of the carbon in the forages is converted into CH_4 in the rumen and released into the atmosphere. The biogenic carbon is constantly being recycled through photosynthesis and digestion by ruminants. Only options that permanently remove carbon from the atmosphere, either in tree vegetation, or with building soil carbon, can qualify for carbon credits.

Why do we account for CH_4 gas (a short-term GHG) the same as we do CO_2 and N_2O (long-term GHGs)?

The IPCC, when developing guidelines for countries to estimate their GHGs, compared all three gases over a 100-year timeframe. The half-life of CH_4 is around 10-12 years, compared to 100+ years for the other two gases. Over a much shorter timeframe, the GWP of CH_4 is significantly higher (~ 84 times more potent than CO_2). A tonne of CH_4 emitted today will break down into CO_2 and water vapour in 10-12 years. Several other metrics have been proposed, including Global Temperature Potential (GTP) (IPCC, 2014) and GWP* (Lynch *et al.* 2020), to better capture the higher GWP of CH_4 over its lifetime as opposed to 100 years. Until the IPCC and UNFCCC (United Nations Framework Convention on Climate Change) determine a different metric, the Australian NGGI will remain using 100-year timeframes for all three gases.

Figure 4 illustrates the result of either increasing, maintaining, or reducing CO_2 and CH_4 emissions on global warming over time. So if we (globally) can stabilise CH_4 production, the tonne produced today replaces the tonne produced 10-12 years ago, thus the net change in CH_4 emissions and global warming attributed to CH_4 will flatline (middle set of graphs). In contrast, even if we were to stabilise CO_2 production today, the tonne of CO_2 produced today builds on the tonne produced yesterday.

Many of the largest dairy exporting countries (NZ, USA, EU) reached an agreement at COP26 in 2021 to reduce CH_4 emissions by 30% by 2030. It must be noted at the time, the then Australian coalition government did not sign this agreement (https://www.abc.net.au/news/2021-11-03/australia-refuses-to-join-global-pledge-to-cut-methane-emissions/100589510, accessed March 2022). This may change in the future with the current Labor government. While much of the initial focus will occur within the fossil fuel and waste management sectors, agriculture will also need to implement policies to reduce CH_4 production.

To slow down global warming, it is imperative that net production of all GHGs are eliminated (right-hand side graphs in Figure 4). This does not mean that production of GHGs must cease, we may never get a net zero GHG-emitting cow. Our future needs to be reflect where residual GHGs are offset with an equal, or preferably greater, rates of carbon sequestration in trees and soils, so that net emissions are zero/beyond zero.

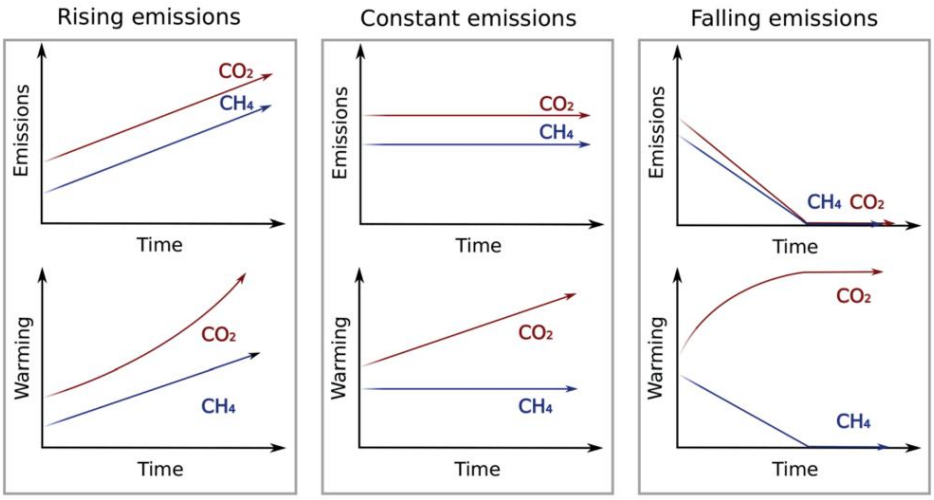


Figure 4. Illustration of the effect of rising, constant or falling carbon dioxide and methane emissions on global warming over time (Source: https://clear.ucdavis.edu/explainers/why-methane-cattle-warms-climate-differently-co2-fossil-fuels, accessed March 2022).

How critical is it that I separate my urea-based N fertiliser out from all other sources of N fertiliser

When urea is manufactured, it takes CO_2 out of the atmosphere. This is then released back into the atmosphere when the fertiliser is applied to land. Where possible, determine the proportion of total N fertiliser derived from urea, keeping in mind that some blends may contain urea as the source of N fertiliser. Each tonne of urea N is equivalent to ~ 1.6 t CO_2e. It's not just urea fertilisers though, it's any urea-based N fertilisers which include Pasture Boosta, Easy-N or UreaS. Ideally, when sourcing blends which contain N, it is good practice to ask your fertiliser supplier if the N is urea or non-urea so we can more accurately capture CO_2 emissions from urea-N based fertilisers.

5. Australian Dairy Carbon Calculator (ADCC)

The ADCC, and its predecessor, the Dairy Greenhouse gas Abatement Strategies (DGAS) calculator, is based on the most currently available Australian NGGI methodology (Australian Government, 2025). In many ways, ADCC is very similar to the University of Melbourne's Greenhouse Accounting Framework (D-GAF; http://www.piccc.org.au/resources/Tools) calculator, and the carbon calculator within Dairy Australia's DairyBase (https://www.dairyaustralia.com.au/farm-business/dairybase/getting-started#.Yfyihd9BwnI). There is also a DairyBase in New Zealand, so when you google DairyBase looking for the Australian version, make sure you are selecting the correct website, located on Dairy Australia's website.

All three Australian dairy GHG calculators are built using the same NGGI methodology, it's essentially the 'same machine under the hood'. While previously there were some differences between the calculators, resulting in differing GHG emissions results, many of those differences have now been resolved. For example, D-GAF previously did not estimate pre-farm embedded emissions associated with key farm inputs such as grain, fodder, and fertiliser. At the time of writing this manual, D-GAF has not allocated a proportion of GHG emissions to meat production; all emissions were attributed to milk production. D-GAF also employs an EI based on milksolids, as opposed to FPCM.

One key difference between the three calculators is that ADCC allows users to explore a range of abatement options to reduce on-farm GHG emissions (see the Carbon Offset Scenario Tool (COST) in section 8). ADCC also allows users to compare the effect of the changing NGGI methodology on 'Your Farm' emissions. For example, for the farm example used in section 5, the current methodology estimates net farm emissions at 3,540 t CO_2e/annum. With the 1990 methodology results were 3,216 t CO_2e/annum, increasing slightly to 3,266 t CO_2e/annum with the 2015 methodology, thus both lower than the current 2025 methodology. However, with the 2022 methodology, net farm emissions were 3,559 t CO_2e/annum, thus higher than current. This is an important insight, as the change in GHG emissions here was solely a result of changing methodology, as opposed to any change in farm practices. Therefore, it's important when reporting either net GHG emission or EI, that the methodology used is also outlined, so that you are comparing 'apples with apples', not 'apples with oranges'.

It is also important to note that ADCC and DairyBase may still lead to slightly different results, due to rounding up/down numbers, determining annual stock numbers, diet quality etc. Likewise, as mentioned above, D-GAF allocates all GHG emissions to milk production, so the estimated result will be greater than those of ADCC or DairyBase. Once you have determined a calculator to use, it is important to remain using this same calculator. This means that results can be compared over several years of assessment for the same farm, or to compare results between farms.

5.1. Where can I access ADCC from?

The ADCC is an excel spreadsheet on the Dairy Australia website, and can be downloaded at https://www.dairyaustralia.com.au/climate-and-environment/greenhouse-gas-emissions/australian-dairy-carbon-calculator. The file should automatically download, and then you can save this to your computer. Once downloaded, you no longer require access to the Dairy Australia website to use the calculator.

5.2. What's different between version 5.4 and 6.1 of ADCC?

In June 2025, we began the process of updating ADCC to incorporate changes to the overall look and feel of the calculator. We have also incorporated several changes as required with updates to the inventory and to remain comparative to DairyBase. These changes are listed near row 125 of the 'Introduction' tab, and include:

- Complete revamp of the colour scheme and restructuring of tabs, including drop-down lists to navigate to other tabs, pulling data from other tabs into the baseline 'Your farm' tab (e.g. fertiliser data or stock sales data), inclusion of a printable baseline 'Your farm' results page, use of a question mark (?) to click on to pull up notes to help with data entry and results interpretation (previously notes would pop up when in a cell with a note which then hid the cell),
- Users can enter the proportion of solids removed via pre-treatment of waste destined for either a pond/lagoon system or spread daily from a sump system (limited to 50%),
- Users determine which non milker stock class is fed on a feedpad and can enter different hours per day, days per year and proportion of each stock class (previously assumed all non- milkers when hours per day and days per year were entered),
- Update of regional, state, national and levels of grain feeding averages based on DFMP and QDAF data from 2019-20 to 2023-24,
- Renaming of 'Baseline farm' tab to 'Your Farm', although in some instances, we still use the wording baseline or baseline 'Your farm' to clarify the difference to the strategy farm,
- Add some functionality to the 'Feed Quality' tab so that within each feed type, you can select the specific feed from a dropdown menu that matches the feed quality table. Once the specific feed is selected, and an amount fed is entered, ADCC populates the average DMD% and CP% as per the feed quality table. The preferred option is to either place a plus (+) or minus (-) sign at the end of the equation and add the value needed to adjust the final value. Alternatively, although not recommended, users can alter the values by either entering the updated value in the table, as this may not be accurate next time, or typing in the correct value, as this removes the lookup functionality.
- Included several new fertilisers into the 'Fertiliser Rates' tab and better estimated the proportion of total N fertiliser that is urea-based. Previously, we were only capturing urea fertilisers, although there are several other N fertilisers that contain urea as some or all of the N source (e.g. UreaS, Easy-N, Pasture Boosta),
- Originally the Feeding Dietary Fats & Oils- Replacing Supplementation abatement followed an ACCU methodology whereby changes in diet crude protein were not accounted for, only changes in enteric CH_4. As this ACCU project is no longer active, we have altered the estimations in this abatement to capture the effect of changing diet CP% on N_2O emissions,
- Inclusion of a 'Profitable Emissions Action Plan' tab (listed as 'Action Plan') and printable 'Action Plan Report'. Through a series of questions, users explore confidence around their data entry, ADCC illustrates where 'Your Farm' is tracking better or worse than the industry average selected, gives users the opportunity to reflect on their ability to make changes and from there, helps users work through a plan to reduce GHG emissions.

5.3. What are some of the limitations of ADCC?

The estimations in ADCC rely on accurate farm data, "rubbish in" equals "rubbish out". The calculator's most sensitive number is the milking herd size. Each additional milking cow can be responsible for ~ 5 to 6 t CO_2e/annum depending on her milk production. Accurate annual milk production for the whole herd is also important as it is one of the major determinants of daily intake and, therefore, daily enteric CH_4 emissions.

The GHG emission estimates are relatively static, and thus for some estimates, farm management can have a diminished impact on results. For example, each tonne of N fertiliser applied results in ~ 3 t CO_2e from direct and indirect N_2O emissions. The calculator does not distinguish whether the total amount was applied once per annum or smaller, more frequent applications. Clearly the risk of losing N to the environment (especially leaching and volatilisation) is greater if applied as 2-3 larger applications vs several smaller applications where the pastures can take up most of the N applied. Likewise, some soils are more conducive to leaching, and thus higher indirect N_2O losses. The NGGI equations have taken a national approach to estimate N_2O losses.

The enteric CH_4 equation is based on daily DM intake, which is driven by milk production, liveweight, and diet DMD%. The equations assume an increase in milk production results from an increase in daily DM intake. Therefore, the calculator does not consider any improvement in feed conversion efficiency of the animal. For example, two cows consume the same amount and quality of feed per day and have the same liveweight. Daisy produces 20 litres/day as a long-term average over her lactation, while Molly produces 21 litres/day as a long-term average over her lactation. In this example, Molly has an increased feed conversion efficiency as she is better at converting feed into milk compared to Daisy. The calculator will estimate that Molly **must** have eaten more feed to produce the extra litre/day, therefore increasing Molly's enteric CH_4 production by approx. 0.16 t CO_2e/annum based on the 'Your Farm' system explore in the manual. One cow in the herd is not going to be noticed, but scale this up to a full farm and if all cows have a greater feed conversion efficiency than the national inventory assumes, whole herd emissions will be greater. We have tried to explore this with a new intervention (*Increased milk production*) where users determine the improvement in milk production achieved through an intervention that *does not* result in an increase in feed intake and thus GHG emissions (see section 8.1). If used in this way, this intervention will not reduce net farm GHG emissions, only emissions intensity.

Several supplementary feeds may reduce enteric CH_4 production. For example, feeding a source of high dietary fat can reduce enteric CH_4 by 3.5% for each 1% increase in overall diet fat content (see Sections 8.5 and 8.6). Another example is a comparison made by Moate *et al.* (2017), finding dairy cattle fed wheat produced significantly less enteric CH_4 than if they were fed either barley or maize grain. The 'Your Farm' tab estimation does not take the diet's fat content, or the grain type into consideration. All diets are assumed to produce 20.7 grams of CH_4 per kg of DMI (Charmley *et al.* 2016).

Similarly, there are pasture species that contain condensed tannins (e.g. Birdsfoot trefoil (*Lotus corniculatus*), sulla (*Hedysarum coronarium*), and plantain (*Plantago lanceolota*) (Min *et al.* 2020; Simon *et al.* 2019)). These species, to varying degrees, can reduce enteric CH_4 production. In addition, some of these species can also reduce N_2O emissions through the binding of proteins, increasing the deposition of N into dung vs urine. Suppose if the DMD% and CP% of the diet with these species is comparative to perennial ryegrass/white clover pastures, and thus milk production per cow also remains the same. In that case, ADCC cannot estimate any reduction in GHG emissions with the alternative pasture species.

The calculator does not estimate soil carbon due to the difficulty of accurate estimates due to spatial and temporal variability. However, on the assumption that the user has either measured data for changes in soil C, or data from other tools such as FullCAM, it is possible to include this data by substituting tree carbon with soil carbon using the 'Carbon sequestered using other tools' option (see Figure 24).

Tree carbon sequestration is based on a regional average for a limited number of tree species. The inclusion of tree carbon sequestration is for illustrative purposes, giving a reasonable estimate. If farmers are keen to better understand the potential to sequester carbon in trees on their farm, we

suggest they seek this information from other tools, such as LOOC-C (https://looc-c.farm/), FullCAM (https://www.industry.gov.au/data-and-publications/full-carbon-accounting-model-fullcam), or from specialist tree carbon service providers.

5.4. Introduction

The data needed to undertake an assessment of farm GHG emissions will come from a range of sources, such as milk production data from your milk factory, herd book data for the number of heifers, receipts from electricity or fertiliser suppliers, stock agent for stock sales data, accountant etc.

Feedback from users of the calculator has indicated it takes around 1-2 hours to complete an assessment, assuming you have most or all of this information at hand. The task can take significantly longer if you need to gather all the information from a range of sources. Part of this time is spent becoming familiar with each question and discerning the required level of detail.

A feature introduced in version 4 of ADCC was the ability to import a DairyBase farm system file into the baseline, now 'Your Farm', tab of ADCC (see section 5.8 for further details). To facilitate this, we needed to introduce macros to run this import. Therefore, when downloading ADCC, saving it to your computer and then opening it for the first time, you will most likely need to enable macros, depending on your current computer security settings. **Warning: Never enable macros in a spreadsheet unless you are sure it can be trusted! Macros in Office documents are a common source of malicious content.** A detailed explanation of how to enable macros is included in Appendix 1 as well as being listed on the 'Introduction' tab (scroll down to approx. row 200).

Once you have enabled macros and you first open ADCC, you will see many tabs/data sheets (Figure 5). The first is the Introduction, and this sheet gives you an overview of the calculator, including a description of how to manage the Abatement strategies (COST) worksheets. Some worksheets are hidden (e.g. data for generating the graphs, and emission factors for GWPs) to protect them from being altered. The order of the tabs matches that of the drop-down listing at the top of the sheet (Figure 6).

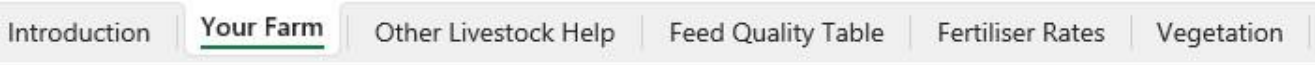


Figure 5. A screenshot of the first few tabs/worksheets in ADCC.

The Introduction sheet, from row 125 onwards, contains a list of changes made between versions of ADCC. In addition to the changes listed, we have included information on how to import a DairyBase datasheet into ADCC and how to disable Macros as required.

Version 6 of ADCC contains around 25 visible tabs (several tabs with graphing data, for example, are hidden). This can make progression through the calculator difficult if the tab you want to access is the most right. A new function of version 6 is the ability to use drop-down lists, found at the top of all tabs, to progress to other tabs within the calculator. On the Introduction, one drop-down list shows all the visible tabs so you can select which tab you which to progress to (Figure 6). The tab you are currently in will be the one visible prior to clicking on the drop-down list.

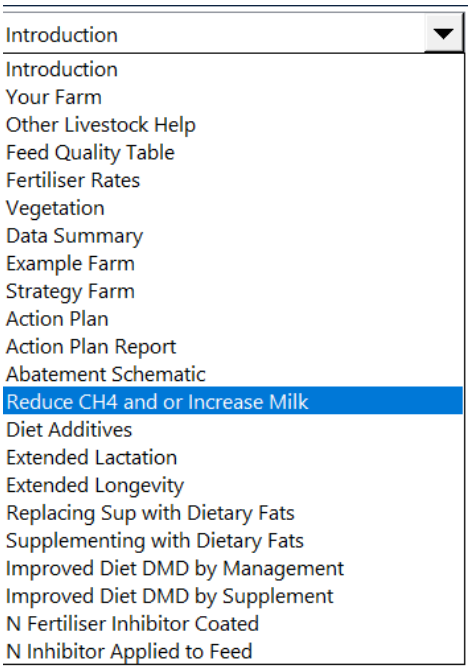


Figure 6. Screenshot of the drop-down list to select the tab to progress to, the 'Reduce CH_4 and or Increase Milk' tab in this example.

On the top of all tabs, users can also hide or make visible some or all tabs by clicking on the second drop-down list (Figure 7). Selecting 'All' will make all 25 tabs visible. However, selecting 'Your Farm' will reduce the number of visible tabs to just nine needed to help with filling in the 'Your Farm' tab (e.g. 'Example Farm', 'Vegetation' and 'Fertiliser Rates' tabs). We have also kept the 'Strategy Farm' tab available when selecting 'Your Farm' as this is a replicate farm that allows for a quick way of changing one or more aspects of the farm system not necessarily related to abating GHG emissions. Selecting 'Compare' from the drop-down list allows users to review their 'Your Farm' ('Your Farm') system emissions with previous methodologies. Lastly, selecting the 'Abatement' option from the drop-down list will make visible the range of abatement strategies incorporated into ADCC. If some of the tabs you expected to see along the tab bar are missing, chances are that you have selected either Your Farm, Compare or Abatement from this drop-down list. Select All and every unhidden tab will become visible. Some tabs are purposely hidden, such as those for creating the graphs or storing the regional average emissions data.

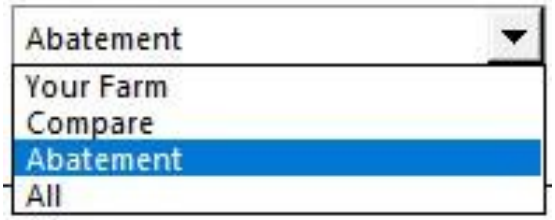


Figure 7. Clicking on the second drop-down list, users can determine which group of tabs to be visible. In this example, 'Abatement' has been selected so only the abatement strategies, along with the 'Your Farm' system and Abatement Schematic tabs are visible. All other tabs are hidden but can be quickly become visible by selecting the 'All' option.

5.5. ‘Your Farm’ data entry

The ‘Your Farm’ tab (previously called ‘Your Farm’) is where you will spend most of your time when using the calculator; its where you enter all the data for the assessment year. When you open ADCC, and progress to the ‘Your Farm’ tab for the first time, all cells will be blank. We have created an ‘Example Farm’ tab to illustrate a typical farm (same as used in section 5 in this manual) as a reference point to understand the data entry required.

With version 6 of ADCC, we have replaced how the help messages are presented. Much of the information remains the same, but is now visible by clicking on the left mouse button when hovering over the question mark located within a circle (Figure 8). A new box will appear with the information, in the same manner as the previous pop-up help message (Figure 9). Click on the x in the top right corner to close the help message. Some pop-up messages will also have a primary ‘Note’ and a ‘More’ tab which contains additional information (e.g. clicking on the Average milk production help button).

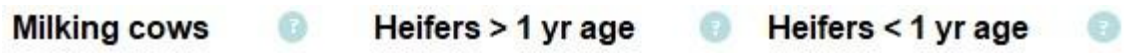


Figure 8. Hover over the blue circle with the question (?) mark to open a new window with the help message text.

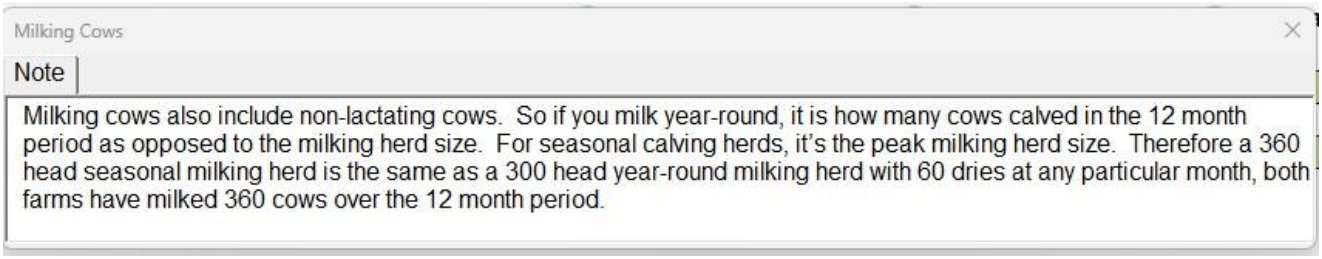


Figure 9. Milking cows help message.

In changing the colouring scheme for version 6 of ADCC, the bulk of each tab is now coloured white with the entry cells now coloured green. In most instances, you will need to enter data in each of the green cells. Some cells require numbers, while others will have a drop-down list. You need to select the most suitable option for your farm assessment.

The only exceptions where you may not need to enter data into green cells for the ‘Your Farm’ tab are if:

- You didn’t have six rows of feed types to determine diet quality (see *Step four*),
- the answer is zero such as you didn’t purchase any supplementary feed for each feed type (see *Step seven*),
- When you do not have trees established on farm to estimate their rate of carbon sequestration (see *Step eight*), or
- When you are using the default state-based factors and fractions for manure management (see *Step nine*).

Step one: Farmer details

Start at the top, working your way across and down the tab. Figure 10 is a screenshot of the farmer’s details. We now allow you to enter who filled in ADCC, which might be yourself, or could be a consultant or accountant. In the example below, you can see that K Christie-Whitehead filled in this farm system and selected ‘Other’ from the dropdown list.

Selecting your state within Australia is critical to determining how the manure (dung and urine) is managed on farm. Choosing your region/farm system comparison is important as ADCC uses this selection to ascertain which region to use when graphing the typical averages bar chart (see Results in

section 5.6). Users can select either their region (Victoria, New South Wales, and Queensland broken down into two or three regions), their state, Australia-wide, or their level of grain feeding. Only the state and region/farm system comparison is used within the calculator, all other data is purely for identification.

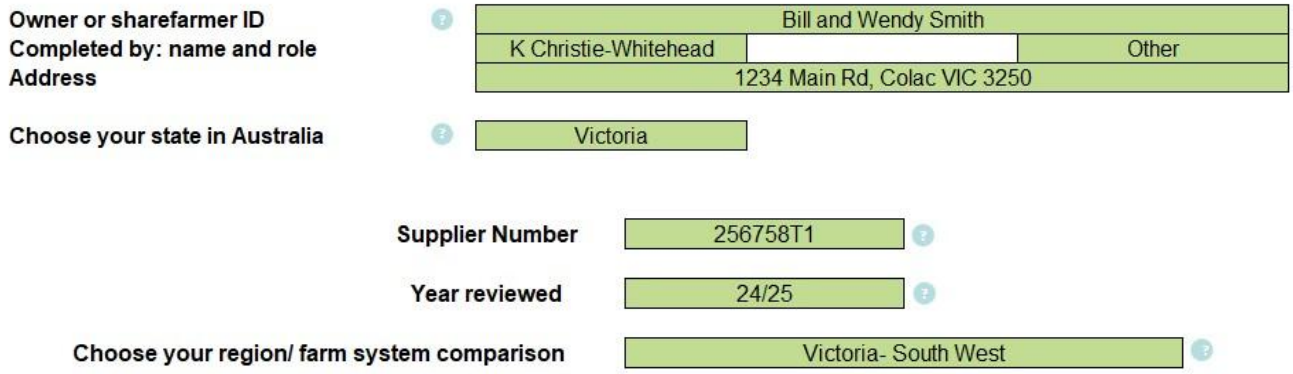


Figure 10. Farmer details section on the 'Your Farm' tab. This farm is in Victoria, to estimate waste emissions, and the results graph will compare this farm with the Victoria- South West average (note this section of data entry has been broken down into two images to make it easier to read the text).

Step two: Livestock numbers, liveweights, and sales data

Livestock numbers

The largest source of on-farm GHG emissions is enteric CH_4. Therefore, entering accurate stock numbers is critical for an accurate assessment. Milking cows number also includes dry cows for the year of assessment. For example, a 360 spring calving herd is the same as a year-round calving herd that milks ~ 300 cows daily and has ~ 60 dry cows present at any time of the year or a split-calving herd with 200 cows calving in spring and 160 cows calving in autumn. Any cow milked for a minimum of two months should be accounted for, even if they were culled prior to the rest of the herd being dried off.

All other stock classes are determined by the average number present over the full 12-month period. For example, displayed in Figure 11, we retained 125 Heifers < 1 yr of age. We also had 125 Heifers > 1 yr of age but after pregnancy testing at 18 months of age, there were 10 non-pregnant heifers. In this example, there was 125 heifers for 6 months (12-18 months of age), and 115 heifers for 6 months (18-24 months of age), thus the annual average was 120 heifers. The 10 non-pregnant heifers were sold at 425 kg liveweight. We retained 100 bull calves (Other stock < 1 yr of age) which were fattened for 12 months before selling at 400 kg liveweight. We also sold 4 bulls at 600 kg, and 115 cull cows at 550 kg liveweight.

If you retained 100 steers each year until they are 24 months of age before selling, then in addition to having 100 steers in the Other stock < 1 yr age class, you also have 100 steers in the Other stock > 1 yr age class. However, if these 100 steers were sold at 21 months of age instead of 24, then you would have 100 steers for 9 months, and 0 steers for 3 months, equivalent to 75 head for the full 12 month assessment (i.e. 100 steers x 9 months + 0 steers x 3 months = 900 steers / 12 months = 75 steers). If you retain your steers for longer than 24 months, you will have one group of steers > 1 yr age, and another group of steers > 2 years of age. For example, you have 100 steers present for the full 12 months (12 to 24 months), and then have another cohort of 100 steers present for 2 months (24 to 26 months), as they are sold at 26 months of age. This would be equivalent to 117 steers present across the 12-month assessment (i.e. 100 1-2 yr old steers x 12 months + 100 2- 3 yr old steers x 2 months = 1400 steers / 12 months = 117 steers).

Liveweight and liveweight gain

Liveweight is the average liveweight for each stock class over the 12-month period. For Heifers < 1 yr and Heifers > 1 yr, it is generally their liveweight at 6 months and 18 months of age. For 'Other stock' in each age group, it will be the average weight for the period they are present on the farm within each stock class. For example, steers were 300 kg at 12 months of age, and sold at 450 kg at 18 months of age, so their average liveweight for Other stock > 1 yr of age would be 375 kg. Milking cow liveweight gain is blanked out. Over the duration of 12 months, the weight they lose in early lactation is regained over the balance of their lactation and dry period. Bull liveweight gain is also blanked out as they are unlikely to gain much weight over a 12 month period.

Liveweight gain is the average weight gain per day over the assessment year. Heifers will gain between around 0.6 and 0.75 kg/day, although steers are likely to have a higher daily liveweight gain. An easy way to estimate liveweight gain might be to work out their liveweight at the end of the 12 months, subtract from this their liveweight at birth, and divide by 365 days. For example, heifers were born at 40 kg, and at 12 months of age were 250 kg, so they put on 210 kg over 365 days, equivalent to 0.6 kg/day. Likewise, the steers put on 150 kg over 6 months, gaining 0.83 kg/day. If the animals are not present for the full 12 months, still determine the difference between the start and end of the assessment and divide by the number of days present. For example, steers put on 100 kg over 75 days equates to 1.33 kg/day.

Typical liveweights for different breeds of dairy cows are presented in Table 1 (values are similar to those implemented in ADCC within DairyBase). Bulls are generally around 10-20% heavier than the milking cow, whereas the Rising 2 and Rising 1 yr olds are approx. 70 and 30% that of the milking cow at their mid-year point (i.e. at 18 and 6 months of age for rising 2 and rising 1 yr olds, respectively). The liveweight gain for smaller breeds, such as Jerseys, is likely to be around 0.45 to 0.5 kg/day, medium size Friesians might be around 0.60 to 0.65 kg/day whereas large Holstein Friesians might be around 0.7 to 0.75 kg/day.

Table 1. Typical average liveweights of dairy cattle breeds.

Breed	Milking cows (kg)	Rising 2 yr olds (kg)	Rising 1 yr olds (kg)
Medium Friesian	550	380	155
Large Friesian	600	415	170
Holstein-Friesian	650	450	185
Friesian crossbred	500	350	145
Jersey	400	275	115
Jersey crossbred	450	315	130
Ayrshire	540	375	150
Guernsey	480	335	140
Brown Swiss	600	415	170
Illawarra/ Aussie Red	550	375	150

Stock sales

A feature of ADCC version 5 is identifying when surplus animals (non-replacement heifers and bull calves) are sold. There is a drop-down list to the right-hand side of the Calves heading in the Livestock dynamics section. If you sell these non-replacement animals soon after birth (i.e. 1-3 weeks post birth), select '*Calve sold soon after birth'*. If you retain them until post-weaning before selling, select '*Calves sold post-weaning'*. In Figure 11, the non-replacement calves were sold post-weaning. If you sell some calves soon after birth, while others post-weaning, determine the average liveweight across both groups of calves. For example, retain 95 heifer calves until they are weaned before selling at 100 kg but sell 120 bull calves at 45 kg, this would be equivalent to selling 215 calves at ~ 70 kg. Although more calves are sold at birth, total liveweight sold was greater with the heifer calves vs bull calves, so select '*Calves sold*

post-weaning' from the drop-down list. If you retained some non-replacement animals post-weaning (e.g. raise heifers to 15 months of age for the export market), these can either be included in the appropriate Heifers or Other stock class. However, if you are exploring the 'Extended lactation' intervention, we highly suggest that any heifers not destined to enter the milking herd are reported in the Other stock class. This ensures an appropriate replacement rate for the milking herd is estimated for the 'Your Farm' system prior to any intervention being explored.

ADCC also now asks questions related to total liveweight sold from all stock classes. This helps to determine net GHG emissions attributed to meat and milk production, and thus the EI of milk and meat. In Figure 11, we sold 115 cull cows at 550 kg, 10 18 month old empty heifers at 425 kg, 4 mature bulls at 600 kg, 100 steers at 400 kg, and 215 calves post-weaning at 105 kg. Thus total meat sold off the farm was 132 tonnes liveweight.

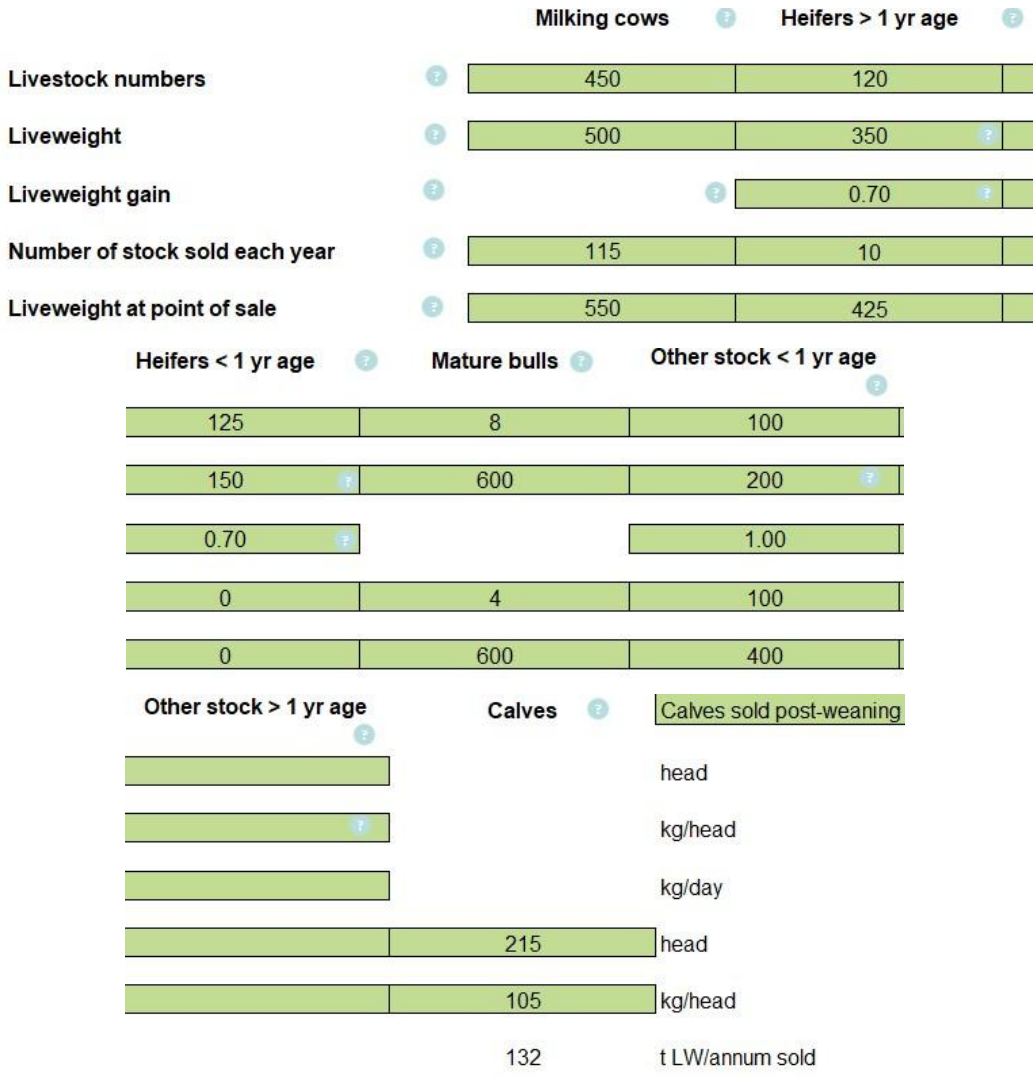


Figure 11. The livestock numbers section for the 'Your Farm' tab (note this section of data entry has been broken down into three images to make it easier to read the text).

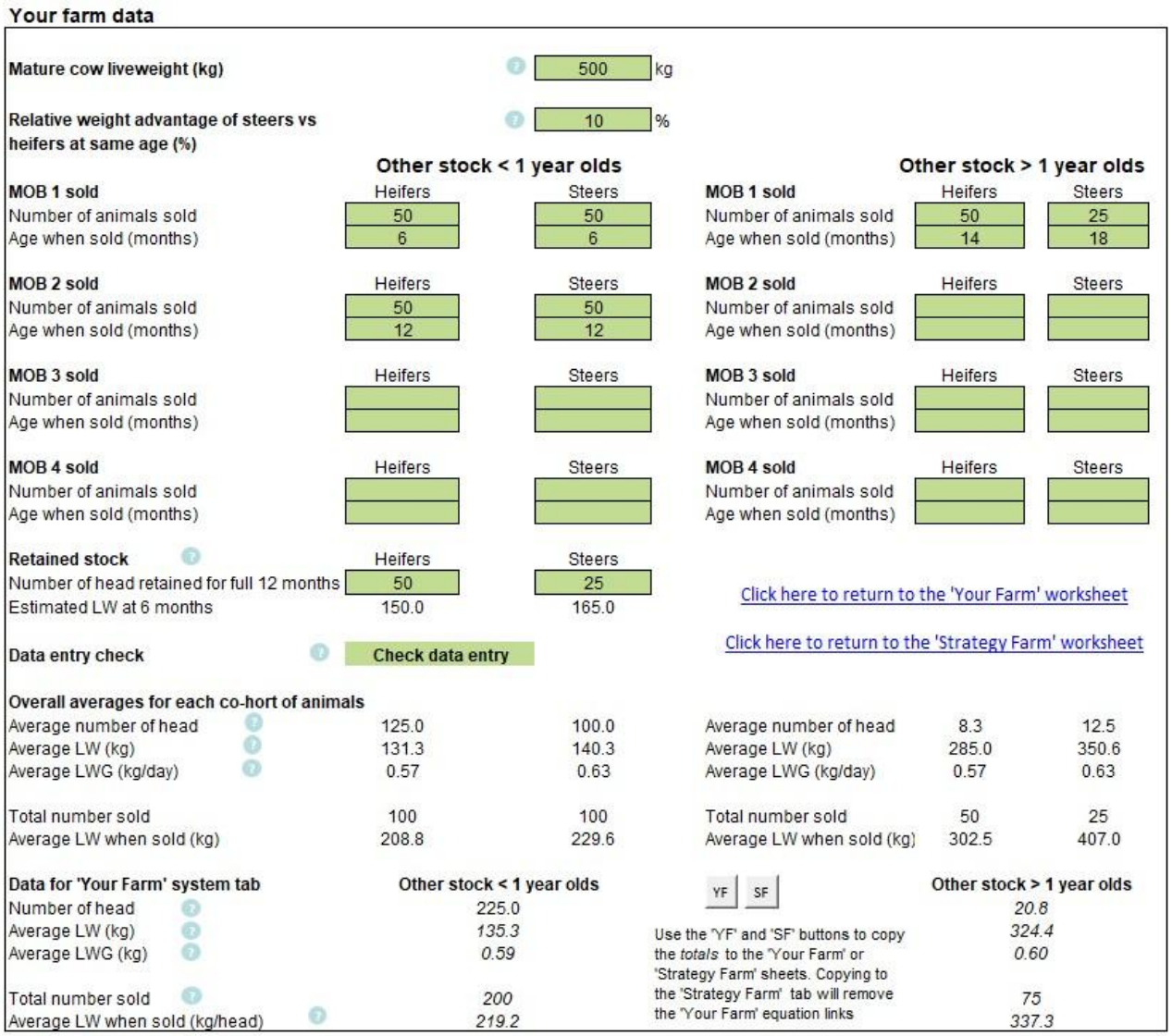
'Other Livestock Help' tab

Determining the average number of Other Livestock and their corresponding liveweight data can be difficult. This tab is designed to estimate the data required for the 'Your Farm' tab given a few critical input values (Figure 12). The help tab is only for the non-replacement heifers and all steers for the Other stock classes in the 'Your Farm' or 'Strategy Farm' tabs. We assumed here that all non-replacement

animals are sold by 30 months of age. Use the Other stock > 1 year olds category for any animals between 24 and 30 months of age. Any calves sold immediately post-weaning should not be entered in the help tab, rather select 'Calves sold post-weaning' from the drop-down list of the ‘Your Farm’ system tab and enter them there. These values are also indicative and if you have more accurate data, you can consider altering the data entry manually. However, depending on how this is undertaken, it could break the equations. Preferably you enter your own-estimated data straight into the ‘Your Farm’ tab.

An example of the help tab (Figure 12) shows that the mature cow weighed 500 kg and the steers had a 10% liveweight advantage over the heifers when at the same age (i.e. at 6 months of age when the first co-hort of animals were sold, the heifers were 150 kg while the steers were 165 kg, thus the difference is 15 kg, and when divided by the heifer liveweight of 150 kg, the steers have a 10% liveweight gain advantage).

In the year of assessment, we sold 50 heifers and 50 steers at 6 months of age, another 50 heifers and 50 steers at 12 months of age, another 50 heifers at 14 months of age and finally 25 steers at 18 months of age. In addition, during the assessment year we held over 50 heifers and 25 steers aged 0 to 1 which would be sold next year. The 12-month weighted number of Other stock < 1 yr of age (heifers + steers) was 225 head, weighing 120.6 kg and average liveweight gain of 0.59 kg/day, while the 12-month weighted number of Other stock > 1 yr of age (heifers + steers) was 20.8 head, weighing 324.4 kg and average liveweight gain of 0.60 kg/day. We also sold 200 head, up to 1 yr of age, at 219.2 kg/head as well as 75 head, aged > 1 yr, at 337.3 kg/head. These values in rows 62 (number of head) to 67 (average LW when sold) need to be entered into the ‘Your Farm’ tab rows 19 to 27. We have also placed an error message so that if the number of heifers or steers sold + retained for next year is greater than the likely number, a message ‘Check data entry’ will appear in a green box, as shown in Figure 12. Otherwise, if the numbers of stock sold and retained seem plausible, this message and green box will disappear. Note that this example here is not meant to match what we currently have for the whole farm example explored throughout this section of the manual.



Your farm data

Mature cow liveweight (kg)	500	kg
Relative weight advantage of steers vs heifers at same age (%)	10	%

Other stock < 1 year olds

MOB 1 sold	Heifers	Steers
Number of animals sold	50	50
Age when sold (months)	6	6

MOB 2 sold	Heifers	Steers
Number of animals sold	50	50
Age when sold (months)	12	12

MOB 3 sold	Heifers	Steers
Number of animals sold		
Age when sold (months)		

MOB 4 sold	Heifers	Steers
Number of animals sold		
Age when sold (months)		

Other stock > 1 year olds

MOB 1 sold	Heifers	Steers
Number of animals sold	50	25
Age when sold (months)	14	18

MOB 2 sold	Heifers	Steers
Number of animals sold		
Age when sold (months)		

MOB 3 sold	Heifers	Steers
Number of animals sold		
Age when sold (months)		

MOB 4 sold	Heifers	Steers
Number of animals sold		
Age when sold (months)		

Retained stock	Heifers	Steers
Number of head retained for full 12 months	50	25
Estimated LW at 6 months	150.0	165.0

Click here to return to the 'Your Farm' worksheet

Click here to return to the 'Strategy Farm' worksheet

Data entry check — **Check data entry**

Overall averages for each co-hort of animals

Average number of head	125.0	100.0
Average LW (kg)	131.3	140.3
Average LWG (kg/day)	0.57	0.63
Total number sold	100	100
Average LW when sold (kg)	208.8	229.6

Average number of head	8.3	12.5
Average LW (kg)	285.0	350.6
Average LWG (kg/day)	0.57	0.63
Total number sold	50	25
Average LW when sold (kg)	302.5	407.0

Data for 'Your Farm' system tab	**Other stock < 1 year olds**	**Other stock > 1 year olds**
Number of head	*225.0*	*20.8*
Average LW (kg)	*135.3*	*324.4*
Average LWG (kg)	*0.59*	*0.60*
Total number sold	*200*	*75*
Average LW when sold (kg/head)	*219.2*	*337.3*

YF SF

Use the 'YF' and 'SF' buttons to copy the *totals* to the 'Your Farm' or 'Strategy Farm' sheets. Copying to the 'Strategy Farm' tab will remove the 'Your Farm' equation links

Figure 12. Example of the 'Other Livestock Help' tab to determine the values required for the Other stock < 1 yr of age and > 1 yr of age for the 'Your Farm'. Some rows and columns have been removed to make it easier to read the text in the image. Data entry here is unrelated to the 'Your Farm' system as there are more young stock sold here than present in the 'Your Farm' system.

Step three: Milk production

There is a drop-down list to select how to enter milk production data:

- litres per herd per annum, or
- kg milksolids per herd per annum.

Select the option you wish to use, then enter total milk production, average fat%, and protein%, with these percentages entered as whole numbers to one decimal point. This is schematically shown in Figure 13, with 4.3 typed in the green cell for fat %. Do not type in 0.043 or 4.3% as this will result in an error in FPCM estimations. Also enter the herd's average lactation length (days), for instance most cows are milked for 300-305 days before drying off. If you implement extended lactations, with cows milked for longer than 365 days, enter 365 into the green cell. This reflects how long the cows have been milked for that year of assessment. An error message will appear if you try to enter a number greater than 365.

ADCC will then estimate daily cow milk production, based on cow numbers, total milk production, and average lactation length. In this example, the average milk production was 22.2 litres per cow per day (circled section in Figure 13). Check to ensure the average milk production per day is reasonable. If not, check data entry and amend as required.

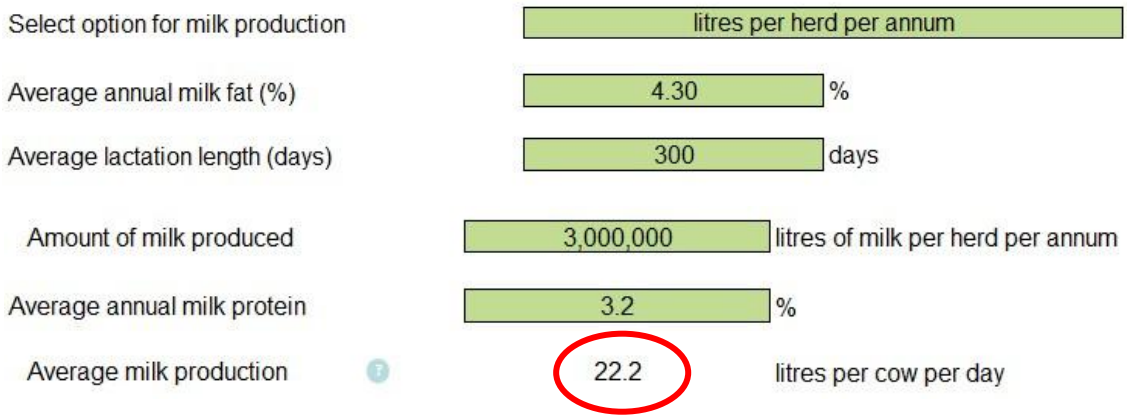


Figure 13. Annual milk production section for the 'Your Farm' tab (note this data entry section has been broken down into two images to make it easier to read the text).

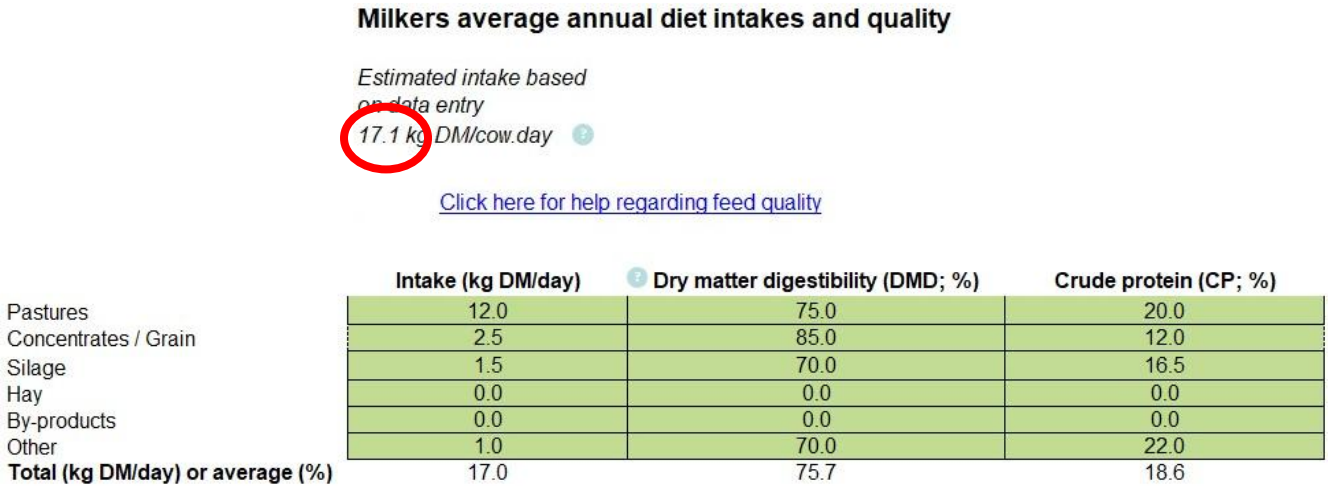
Step four: Average diet intakes and quality

The ADCC needs relatively accurate diet digestibility (DMD) and crude protein (CP) data to estimate CH_4 and N_2O emissions. The easiest way to enter data here is to enter all the supplementary feed intakes (kg DM/day), taking into consideration wastage (i.e. ~ 1-2% for grain/concentrates, possibly up to 15% for silage and hay fed in the paddock), and quality. Click on the link in the green box on the left-hand side of this section if you are unsure of the feed quality information for each supplementary feed (circled in red in Figure 14 below). This action will lead you to a new tab within ADCC, where there is a table of feeds, and their corresponding feed quality ranges to use as estimates. The 'Feed Quality' tab can also help you convert megajoules of energy (ME; MJ/kg dry matter) to DMD%. Additionally, the 'Feed Quality' tab can also help to determine the average feed quality for each feed type if you feed more than one. For example, feeding 2 kg of wheat with a CP of 12%, and 1 kg of lupins with a CP of 32%, equates to 3 kg of grain with a CP of 19.3%.

Once you have entered all supplementary feed, and their corresponding DMD and CP%, enter the average annual pasture DMD and CP%. If you have no idea of your pasture DMD and CP%, we suggest you enter 75 and 20, respectively, as these are the defaults used within the NGGI methodology, based on research by Christie *et al.* (2012).

ADCC estimates the potential total diet intake based on average annual milk production and diet DMD%. Daily intake is shown in italics on the left-hand side of the diet intakes and quality section, just above the red circle in Figure 14. If the amount of pasture consumed is not known, you can subtract the total amount of supplementary feed from this total intake to determine pasture intake. To illustrate on this farm example, ADCC estimated the cows required 17.1 kg DM/cow to produce 22.2 litres/day for 300 days. The milkers were fed 2.5 kg DM per day as grain/concentrate, 1.5 kg DM per day as silage, and 1.0 kg DM per day of brewer's grain after wastage was taken into consideration. Therefore ADCC estimated the cows would require 12 kg DM of pasture per day (Figure 14).

Note: this section is only determining the overall diet DMD and CP% of the milker diet which is then also used for the dry period for the milking cow. While it is noted that dry cow diets are generally lower in quality, the sensitivity of feed quality on overall GHG emissions is relatively low. Thus, having two feed qualities, one during the lactation phase, and one during the non-lactating phase, is unnecessary. Daily intakes, including the dry period, to estimate GHG emissions (e.g. enteric CH_4 emissions) are estimated using other data, such as milk production and liveweights.



Milkers average annual diet intakes and quality

Estimated intake based on data entry
17.1 kg DM/cow.day

Click here for help regarding feed quality

	Intake (kg DM/day)	Dry matter digestibility (DMD; %)	Crude protein (CP; %)
Pastures	12.0	75.0	20.0
Concentrates / Grain	2.5	85.0	12.0
Silage	1.5	70.0	16.5
Hay	0.0	0.0	0.0
By-products	0.0	0.0	0.0
Other	1.0	70.0	22.0
Total (kg DM/day) or average (%)	17.0	75.7	18.6

Figure 14. Milker average intakes and feed quality section for the 'Your Farm' system (note this data entry section has been broken down into two images to make it easier to read the text).

If you require help with determining feed quality values, or you have a complex blend of supplementary feeds, such as a blend of different concentrates and grains that goes into a feed wagon, by clicking on the blue **Click here for help regarding feed quality** text. This will take you to a new tab to determine annual average amounts, DMD and CP%. For example, in Figure 15, we fed 1 kg of maize grain and 2 kg of wheat grain. By selecting these grains from the drop-down list, the average DMD % and CP % will be populated from the feed quality tables in the same tab. If you know the DMD % and CP % values of the supplementary feeds and the values populated are incorrect, for example, you know the maize grain is 12% CP, the best way is to click in the cell and change the equation so that the result matches. In this example, the cell reference for maize grain CP has the equation = I11, so in there, type in =I11+2 which will change the 10 % to 12 %. Alternatively, you can type 12 in cell R36. Then when you click on the Copy button in the top left corner of the Grain/concentrate section, this transfers to the appropriate location in the feed quality table in the 'Your Farm' tab.

Enter your farm data here

Use the 'Copy' button to copy the totals to the 'Your Farm' sheet. The 'Clear' button clears the input area. This includes clearing the function of pre-filling typical average DMD and CP values from the tables. You might be better to just clear the kg amounts. Values copied into the 'Your Farm' sheet will be in italics.

Copy Clear	Description	Amount (kg DM/cow.day)	Dry matter digestibility (DMD; %)	Crude protein (CP; %)
Grain/concentrate 1	Maize grain	1.0	89.2	10.0
Grain/concentrate 2	Wheat grain	2.0	84.7	12.9
Grain/concentrate 3				
Grain/concentrate 4				
Grain/concentrate 5				
Grain/concentrate 6				
Total and average		*3.0*	*86.2*	*11.9*

Figure 15. Example of how the feed quality table tab can help you determine the total amount and average dry matter digestibility and crude protein percentages. Tables are also set up for silage, hay, and other feeds/by-products.

ADCC also requires the feed quality for all other stock classes. We have not distinguished between stock classes here, for example, rising 1 yr olds receive grain and thus their diet quality is higher than the steers being fattened. If unsure of the feed quality, use the defaults of 75% DMD and 20% CP as these are implemented in the NGGI methodology (Figure 16), as per Christie *et al.* (2012).

Average annual dry matter digestibility (DMD) for all other stock (%)	75.0	%
Average annual crude protein (CP) for all other stock (%)	20.0	%

Figure 16. Recommended DMD % and CP % for all other stock.

Step five: Fertiliser inputs

Fertiliser inputs are used to estimate N_2O emissions from the application of fertilisers, CO_2 emissions from lime and urea, and the pre-farm embedded Scope 3 emissions from the manufacturing of these fertilisers. To keep it simple, ADCC only mentions lime, but if you are also applying dolomite to pastures and/or crops, include this amount as you would for lime.

ADCC gives you two options for entering fertiliser input data from a drop-down list:

- tonnes of element per annum (e.g. 15 t of N/annum, 3.5 t of P/annum etc), or
- kg of element per hectare per annum (e.g. 225 kg N/ha.annum, 125 kg P/ha.annum etc).

Whichever option is selected, you need to use this for all fertiliser data entry. We are also asking for either tonnes or kg of element (i.e. N or P), not per product (i.e. urea or single superphosphate). If you do not know the percentage of element(s) in each product (e.g. urea is 46% N), then use the help option by clicking on the 'Click here to work out fertiliser rates' cell (highlighted by a red circle in Figure 17). This will take you to a new worksheet to help estimate total tonnes of element per annum from a range of fertilisers, including entering your own blends.

If you select *'tonnes of element per annum'*, you only enter data on the right-hand side of this section (Figure 17. The green cells for the *Area of pastures and crops fertilised* questions (left hand side of data entry) will turn white to further indicate that data here is not required.

In this example, we applied 55 t N/annum to pastures across the whole farm (remember to include fertilisers applied to your outblock or runoff block too), 10 t P/annum, 3 t K/annum, 3 t S/annum, and 150 t lime/annum. We also need to determine the percentage of N fertiliser that is urea for the CO_2 released when applied to pastures and crops. In Figure 17, 95% of the 55 t of N was from urea, with the balance 5% of N included in di-ammonium phosphate (DAP). All other non-urea N fertilisers (e.g. SOA, DAP, MAP) do not release CO_2 when applied to pastures and crops as atmospheric CO_2 was not incorporated into these fertilisers when manufactured.

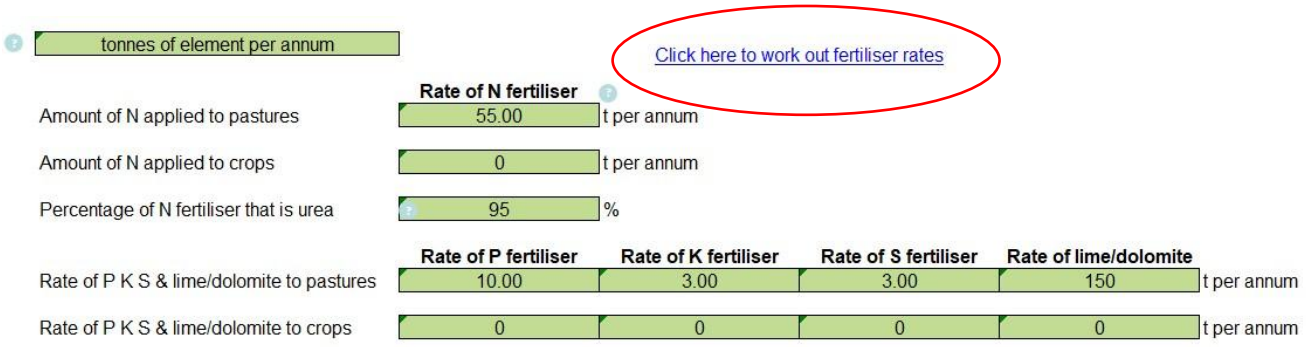


Figure 17. Fertiliser inputs when selecting the tonnes of element per annum option. The red circle shows a hyperlink to the help tad to determine fertiliser inputs if required.

If you select *'kg of element per hectare per annum'* from the drop-down list, you need to fill in the whole *Fertilisers* section (Figure 18). The *Area of pastures and crops fertilised* cells while transition from white to green to indicate that they require data to be entered.

You will need to determine the area of pasture fertilised with N, the rate of N, and the percentage of total N fertiliser from urea. This step needs to be repeated for P, K, S, and Lime. It becomes a bit harder with this option if you have different areas for each nutrient. In this instance, it may be easier to multiply each element by the area applied and enter this as tonnes of element per annum. In shown in Figure 18 below, 220 kg N/ha was applied to 250 ha of pastures, with urea being 95% of the total N fertiliser applied. In addition, 125 ha of pastures had 80 kg P, 24 kg K, 24 kg S, and 1,200 kg lime per hectare applied. Multiplying rate of fertiliser by area applied, in this example, gives the same result as the total tonnes per annum, i.e. 55 t of N, 10 t P, 3 t of K and S and 150 t of lime.

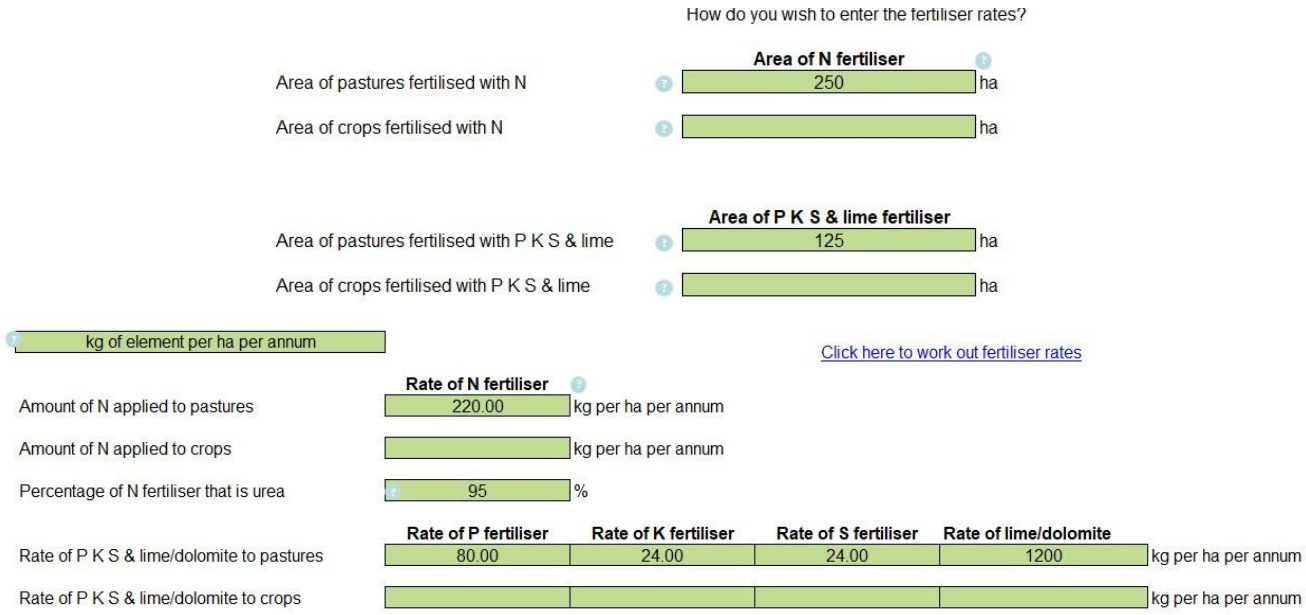


Figure 18. Fertiliser inputs when selecting the kg of element per hectare per annum option (note this data entry section has been broken down into two images to make it easier to read the text).

For fertilisers that are not applied every year, such as lime, entering the total amount purchased in any year will be much greater than if divided over the number of years between purchasing and applying to land. For example, you apply 3 tonnes of lime per hectare across your whole 250 hectare farm every 5th year, thus lime purchased this assessment year is 750 tonnes. If you enter 750 tonnes or 3000 kg across 250 ha, all the emissions associated with production and application to land will be counted in this year's estimate, equivalent to ~ 350 t CO_2e. A better method would be to divide the total amount

purchased by the number of years between applications, so 750 tonnes divided 5 years = 125 tonnes of lime per annum, equivalent to 58 t CO_2e/annum. If this option is elected, you must then report this same rate of lime for the next 4 years otherwise you are misrepresenting the emissions associated with lime applications. If, however, you apply 3 tonnes of lime/ha to 1/5th of the land area each year (50 ha in this example), the total amount of lime remains 150 tonnes per annum.

Step six: Energy consumption

Electricity consumption

Enter your total electricity consumption for the dairy shed, irrigation, water supply, fences, workshop, calf shed etc. We don't need the power for your private home or those of your employees. Use the drop-down list to select the source as either:

- state grid, or
- 100% renewable.

If a proportion of your electricity is from renewable sources, such as your supplier guarantees a percentage is from renewable sources, select '*State Grid'*, enter the total amount of electricity purchased, and the percentage from renewables. For example, my supplier guarantees that 10% is from renewables. If your business consumed 175,000 kWh of electricity in the 12 month period, 90% would have a carbon footprint, based on the state grid emission factor, and the balance 10% from renewables will have a zero carbon footprint (Figure 19).

NOTE: previously we used to subtract any home-generated renewable electricity that was fed back into the grid. After lengthy conversations within Dairy Australia and external experts, a decision was reached that this should no longer be undertaken. The comments associated with electricity consumption have been altered accordingly.

Figure 19. Electricity consumption, source (State Grid), and percentage from renewable sources (10%). Thus, ADCC will work out the emissions associated with 90% of the 175,000 kWh purchased.

<u>Diesel consumption</u>

Enter the amount of diesel/unleaded petrol purchased and via contractors for the whole farm (Figure 20).

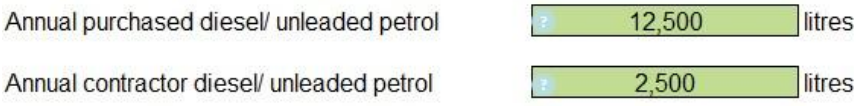


Figure 20. Fuel purchased by the farmer (12,500 litres) plus an estimate of the amount of fuel used by contractors (2,500 litres).

Many dairy farms use contractors for some/all field work such as fertiliser spreading, silage making, paddock renovation etc. It is important to try and estimate how much fuel they may use with these operations, as these activities are part of your farm business. When you hover over the Annual Diesel/unleaded petrol text, there is a help message with estimates of consumption per hectare (Figure 21).

An example may be that a farmer used a contractor to fertilise 100 ha, 3 times per year, so 100 ha x 3 times/ annum x 3 litres of diesel/ ha = 900 litres of diesel. Another example is that 50 hectares was cut, tedded, raked, baled, and wrapped as silage. Thus, 50 ha x 9 litres for mowing, 50 ha x 3 litres for tedding, 50 ha x 3 litres for raking, 50 ha x 16 litres for baling and 50 ha x 9 litres for silage wrapping = 2,000 litres of diesel. If an activity is not listed in the help message, identify a similar activity, remembering that the harder a tractor needs to work, the more fuel consumed per hectare.

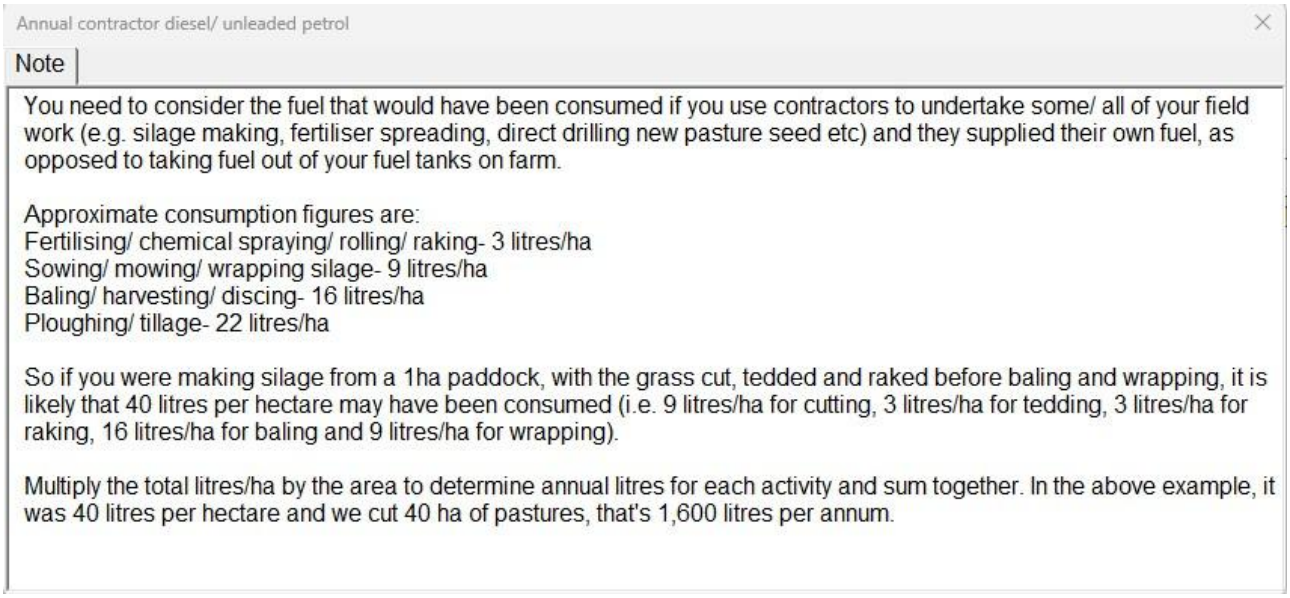


Figure 21. Approximation of the amount of diesel consumed per hectare for typical paddock operations.

Step seven: Purchased supplementary feed

Enter the amount of purchased supplementary feed for the year of analysis. If you have two have two businesses, a dairy farm and a cropping farm and the emissions for the cropping farm is included in the dairy emissions (e.g. fuel for harvesting or transferring plus fertilisers applied to the cropping area), this does not constitute purchased supplementary feed, as the emissions have already been included in the dairy assessment. However, if the emissions of the cropping farm are not included in the dairy farm emission estimates, enter the amounts of supplementary feed 'purchased' from the cropping farm. This ensures that the emissions for amount of product coming from the cropping farm are accounted for.

The amount of feed purchased is multiplied by an emission factor to estimate the pre-farm embedded Scope 3 emissions associated with the production of these feeds. In the example below, the farm purchased 200 t DM of pasture hay, 700 t DM of grain/concentrates and 180 t DM of by-products (Figure 22).

If you are entering data from scratch (i.e., not via the importing of a ADCC spreadsheet from DairyBase) and you purchased a large amount of supplementary feed towards the end of the assessment year, you could consider transferring this purchase to the following year of assessment to better reflect when that purchased feed was consumed on farm. However, it would be critical that you make thorough notes to remember doing this next year.

If you have imported a spreadsheet from DairyBase, ADCC will determine the GHG emissions of all purchased supplementary feed, irrespective of whether fed during the assessment year or a subsequent year.

So that the GHG emissions associated with purchased grain/concentrates, hay and silage supplements are correctly attributed to either milk or meat production (previously we attributed all GHG emissions from fodder production to the dairy herd), you now need to determine the percentage of each supplementary feed fed on the milking platform, ADCC will assume the balance is fed on the support

block. In the example below, 15% of the purchased hay and 95% of the grain/concentrates and by-products were fed on the milking platform (Figure 22).

Some purchased feed, while fed on the support block, may be fed to dairy-enterprise animals, e.g. hay to dry cows. In this instance, we recommend you still attribute the hay fed to these dry cows as being fed on the support block. ADCC will then attribute a proportion of hay emissions back to the dairy enterprise to reflect that some of the hay was fed to milk enterprise animals. The only time we would change this recommendation would be if all purchased feed for any category goes to dairy-enterprise animals, even though it was fed on the support block. In that instance, we would recommend you allocate 100% of the feed being fed on the milking platform so that all emissions are attributed to the milk enterprise.

If you still have any purchased feed left over at the end of the year being analysed, the emissions for these will be accounted for in this year's assessment. In this instance, still work out the proportion of feed fed this year on the milking platform vs support block. For example, bought 100 t DM of hay, with 75 t DM fed on the support block, 20 t DM fed in the calf shed and the remaining 5 t DM held over until next year. In this instance, you would allocate 21% to the milking platform (i.e. 20 t DM fed in the calf shed/ 95 t DM fed across the whole farm = 21% fed on the milking platform).

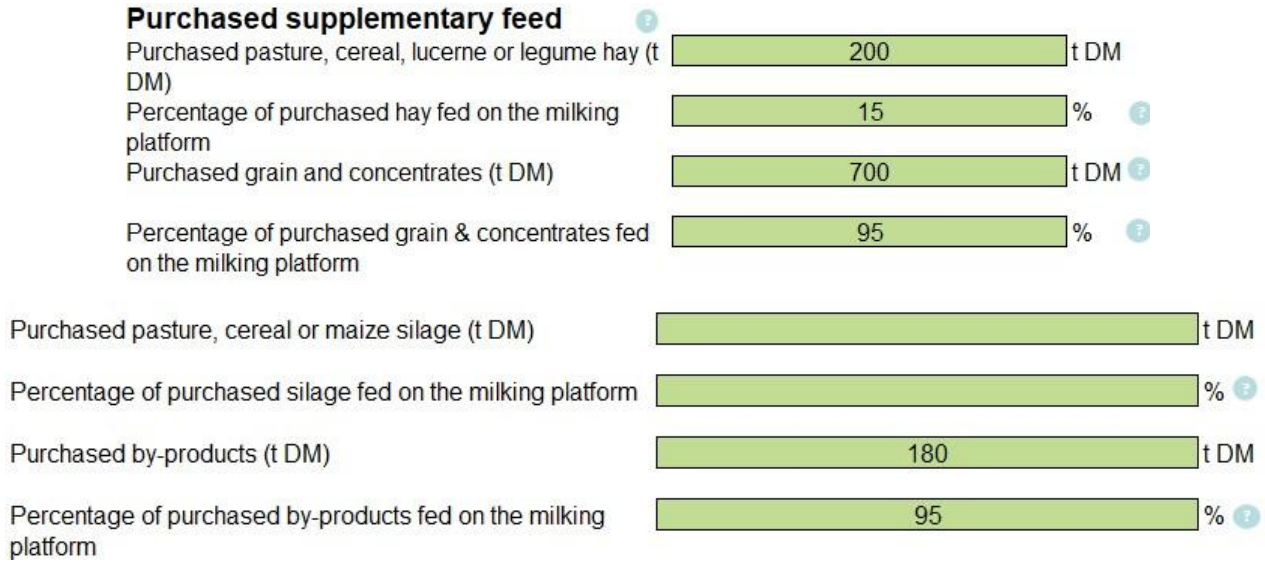


Figure 22. Screenshot of the purchased supplementary feed inputs. This image shows that you purchased 200 t DM of hay, with 15% fed on the milking platform, thus the balance 85% was fed on the support block. You also purchased 700 t DM of grain and 180 t DM of by-products, with 95% of each fed on the milking platform (the data entry section has been broken down into two images to make it easier to read the text).

Step eight: Carbon sequestration in trees

Due to the structure of the equations aligned with the carbon sequestration drop-down lists, please work down the tab, entering how you are calculating carbon sequestration, then region, tree type and finally soil type before entering area and age of trees.

ADCC gives you three options for determining the amount of carbon sequestered in trees on the farm. These are:

- No estimation of carbon sequestration,
- Based on data entered here, or
- Carbon sequestered using other tools

The first option is the default option when opening up ADCC, which results in zero carbon sequestration in trees.

The second option (*Based on data entered here*) requires you to select the appropriate answer from a series of drop-down lists:

- Region of Australia (the number of options available will depend on state selected at the start of the assessment, e.g. Victoria is divided into six regions),
- Type of trees planted (four to six options for each region),

NOTE due to feedback and the lack of difference between soil type for most region by tree combination, we have removed soil type as a data entry. At this stage, we have left the structure of the equations in place at the bottom of the tab (hidden from users) in case this needs to be reinstated in the future.

You then need to enter the area of trees (hectares), and the average age of the trees (in whole years). In the Figure 23 example below, there was 10 ha of 15 year old Mixed species (Environmental plantings) planted in South West VIC. The drop-down list will only select regions based on your state, so if you selected at the top of the tab that you are in Victoria, you won't be able to select your region as being Northern NSW and the list of tree species for that region.

Most regions are relative distinct in terms of selecting the region within the state. However, the three Victorian regions of the Mallee, Northern, and North East may be a little bit harder to select, especially if the farm is close to a regional boundary. We have added a few examples of towns within each region. These can be found by hovering over the Choose your region in Australia text. If unsure, select one region, review the results, then select the other region, and review those results. The amount of carbon sequestered can be substantially lower in the Mallee vs the other two regions. Notice that while there are two soil types for each region, the amount of carbon sequestered in trees remains relatively similar for both. Therefore, selecting the correct soil type is less critical than region or tree species.

The tree species list differs from previous versions of ADCC, and only contains a few options. If your species is not present, select a similar option or the default Mixed species (Environmental Plantings) which is a blend of native trees, shrubs, and understory vegetation endemic to your region. Make sure you start from the top, and work down the tab, as excel needs to know the region of Australia to then determine the type of trees and soil type option available for that region. Working up the tab will result in either errors or zero carbon sequestration results. If using the *Based on data entered here* option, and you have populated ADCC via importing a downloaded spreadsheet from DairyBase, ADCC will automatically populate the cell aligned to 'Amount of carbon sequestered using other tools'. However, if you are starting from scratch and have cleared the input cells, this cell will be blank as currently shown in Figure 23.

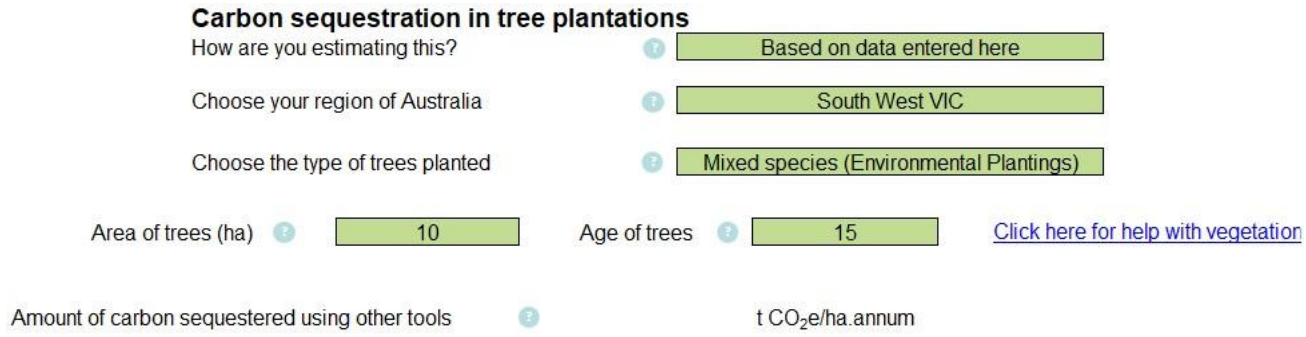


Figure 23. Screenshot of the data entry when selecting the estimation is Based on data entered here (note this section of data entry has been broken down into two images to make it easier to read the text).

If you select the third option of '*Carbon sequestered using other tools'* from the drop-down list, you will need to determine the area of the tree plantings but more importantly, the amount of carbon

sequestered using other tools or calculators (Figure 24). For instance, you may use the FullCAM model https://www.dcceew.gov.au/climate-change/publications/full-carbon-accounting-model-fullcam) or the LOOC-C online tool (https://looc-c.farm/) to determine the likely amount of CO_2e sequestered on your farm with your tree species. In that case, you will only enter the amount of CO_2 sequestered, and the area of trees planted; the Age of trees cell will revert to being a white cell with no border to indicate that this cell does not require any data (i.e. note there is no border or green cell to the right of the Age of Trees heading). In the below example, LOOC-C estimated that the 10 ha of trees sequestered 6.5 t CO_2e/ha.annum, thus 65 t CO_2e/annum. **NOTE** other calculators may report the change in carbon as tonnes of carbon as opposed to CO_2e (e.g. FullCAM). To convert from tonnes of carbon to tonnes of CO_2e, multiply the tonnes of carbon by 3.67 (e.g. 5 t C/ha.annum = 18.35 t CO_2e/ha.annum).

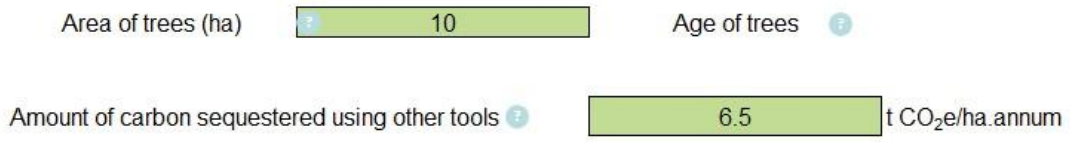


Figure 24. Screenshot of the data needed to be entered if you select to estimate the Carbon sequestered using other tools option from the first drop-down list. Note that the box to the right of Age of trees has disappeared and the cell is now white to indicate that we do not need to enter the age of the trees here.

Feedback from users have told us that for some farms, they may have several areas of land, with potentially different species and/or ages. We have built in a new tab called 'Vegetation' to estimate tree carbon sequestration for up to four areas (Figure 25).

Make sure you enter from the top and work your way down the tab as altering the tree species before you alter the state or region within a state may result in an error. If using this option, enter the necessary data to estimate the total tonnes sequestered. Copy the amount, then go back to the 'Your Farm' tab, select *'Carbon sequestered using other tools*' from the drop-down list, enter 1 ha of trees and paste the result in cell D32 from here into the 'Amount of carbon sequestered if using other tools' cell in ADCC. This will now appear in the Carbon sequestration row of results. If the value in the 'Your Farm' results (keeping in mind the carbon sequestered is presented as a negative value in the results), is different than here, check you have only entered 1 ha of trees and that you have selected '*Carbon sequestered using other tools*'. You won't need to select your region, tree species, or enter Age of trees.

In the example below (Figure 25), we had 2.5 ha of five year old Mixed species sequestering 2.46 t CO_2e/ha.annum (estimated within ADCC), 5.8 ha of eight year old Tasmanian Blue Gums sequestering 2.0 t CO_2e/ha.annum (estimated within ADCC) and 10 ha of Acacias planted 15 years ago and according to FullCAM, sequestered 3.7 t CO_2e/ha.annum between year 14 and 15. The average sequestration rate across the 18.3 hectares was 3.06 t CO_2e/ha, resulting in a total sequestration of 55.9 t CO_2e/annum. Therefore copy the 18.3 ha and 3.06 t CO_2e/ha.annum back into the 'Your Farm' tab so that total sequestration is 55.9 t CO_2e/annum.

Area 1	State	VIC	
	Region	South West VIC	
	Species of tree	Mixed species (Environmental Plantings)	
	Area of trees	2.5	ha
	Age of trees	5	years

Area 2	State	VIC	
	Region	South West VIC	
	Species of tree	Tasmanian Blue Gum	
	Area of trees	5.8	ha
	Age of trees	8	years

Area 5	Area of trees	10	ha
	Age of trees	15	years
	Sequestration rate	3.7	t CO_2e/ha.annum

Tonnes sequestered	Area 1	2.46	t CO_2e/ha
	Area 2	2.20	t CO_2e/ha
	Area 3		t CO_2e/ha
	Area 4		t CO_2e/ha
	Area 5	3.70	t CO_2e/ha
	Area 6		t CO_2e/ha
	Area 7		t CO_2e/ha
	Total hectares	**18.30**	ha
	Average carbon sequestered	**3.06**	t CO_2e/ha
	Average tree age across the farm	11.42	years
	Total across the farm	**55.9**	t CO_2e/annum

Figure 25. Screenshot of the ability to explore up to four areas of farm in terms of vegetation carbon sequestration. Note that we have hidden rows not required for this example.

The estimation of carbon sequestered using ADCC is only indicative, it cannot be used as a surrogate for participating in carbon credit schemes such as the Federal Government's *Reforestation by Environmental or Mallee Plantings-FullCAM methodology*, or non-government schemes.

You could use Carbon sequestration in trees as a surrogate for soil carbon sequestration. For example, you have soil tests to confirm that your farm's soil carbon stocks have increased from 95.0 t C/ha to 95.2 t C/ha over the last 12 months. The net change in soil carbon stocks is a soil carbon flux of 0.2 t C/ha.annum. It is the annual carbon flux we need to include here, not carbon stocks. Select '*Carbon sequestered using other tools'* from the drop-down list, enter the amount of carbon sequestered/ha.annum, keeping in mind that you need to convert from t C/ha to t CO_2e/ha, and enter the area of the farm in the Area of trees cell. For example, my 100 ha farm was estimated to sequester 0.2 t C/ha.annum in the top 30cm of soil profile. Firstly, multiply 0.2 by 3.67 to convert from t C to t CO_2e. Enter 100 ha in the Area of trees cell and 0.734 in the t CO_2e/ha.annum cell, and ADCC will estimate that the soil sequestered 73.4 t CO_2e/annum across the whole farm (i.e., 0.2 x 3.67 x 100).

Step nine: Manure management

The NGGI methodology uses a range of previous information, such as Dairy Australia's Natural Resource Management surveys, to determine the amount of manure (dung and urine) deposited and managed by several manure management systems (MMS). Around 80-85% of all manure is assumed to be deposited onto pastures and crops as the animals are grazing or in the lane ways to and from the dairy. The balance is divided between an anaerobic pond/lagoon system, a sump dispersal system, drains to the paddock, and solid storage. The more anaerobic a manure system is (e.g. pond/lagoon systems), the more CH_4 is produced. Users decide if they wish to estimate their GHG emissions from a drop-down list:

- Default state-based factors and fractions, or
- User-defined factors and fractions

If you select the first '*Default state-based'* option, ADCC will populate the next few rows, illustrating how much manure will be assumed to go to each MMS (Figure 26). Most manure is allocated to pastures, then the lagoon system, with lesser amounts to the other three systems. This is the average for the whole state, so even though you may only have the first two options, there are other farms with other MMS options, such as the sump dispersal system, based on Dairy Australia's surveys. For most predominantly grazing pasture-based farms, the state-based fractions will be relatively accurate for your farm system, reflecting cows are off pastures for 3-4 hours per day for milking. You have now completed data entry, so progress to the results section. Entering data in any of the subsequent questions will not change farm emissions.

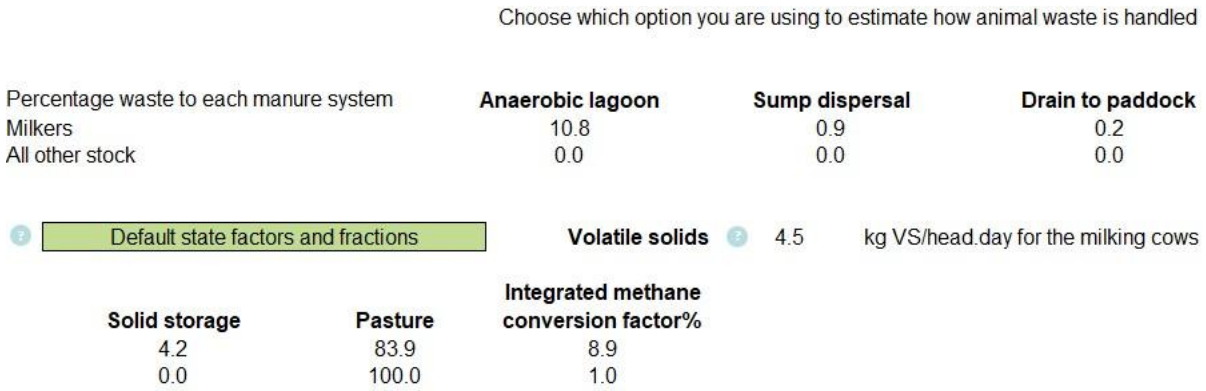


Figure 26. Selecting the default state factors and fractions will determine the proportion of manure to each of the management systems. This reflects cows spending 3 to 4 hours per day at the dairy while all other stock deposit their manure onto pastures. Note that these cells are white, thus they do not need filling in (also note this section of data entry has been broken down into two images to make it easier to read the text note this section of data entry has been broken down into two images to make it easier to read the text).

However, if your milking herd spends substantially extended periods on a feedpad system for supplementary feeding (i.e. partial mixed ration farms) or housed (TMR farms), you should explore the implications of how your manure is managed (Figure 27). This is done by selecting '*User-defined factors and fractions'* from the drop-down list. This will remove the state-based default factors and those cells as shown in Figure 26 above.

You are now required to answer a series of questions to determine how long the milking herd is at the dairy, how the dairy manure is managed, how long the milking herd is on a feedlot, and how the feedlot manure is managed. There are plenty of help messages for this section, which can be accessed by hovering over each question.

While we have indicated two categories of where the manure is deposited, the dairy and a feedpad, you could consider it as what are the two ways in which the manure is managed? If all the captured manure from the dairy, yards and feedpad are flushed to a pond/lagoon system, thus could be all entered in the 'At the dairy section', especially if the balance of the cow's time is spent on a loafing pad or in a compost barn structure where the bedding and manure is frequently in an aerobic state (exposed to air) as opposed to an anaerobic state (absence of air such as in the lagoon). In this case, the manure deposited on the loafing area or bedding has a similar rate of loss of emissions as the 'Scraped & stockpiled' category.

For example, TMR housed cows are at the dairy and yards for 3 hours per day for 300 days. They return to the barn and spend another 5 hours per day for 300 days in the feeding lane of the barn (cows typically up and feeding 5-8 hours over a 24 hour period when housed), with all this manure flushed to a

pond/lagoon system. This equates to 8 hours per day for 300 days. The balance 16 hours per day, the cows are resting/ruminating while laying on a bedding area where the bedding and manure (compost) is turned periodically, thus remaining aerobic. This 16 hours per day for 300 days is entered into the feedpad section, with the manure 'Scraped & stockpiled' option selected. If the cows then go out onto pasture during their dry period, ADCC will allocate the balance 24 hours per day for 65 days to pasture. If there was some form of pre-treatment of the manure as it is flushed to the lagoon system, this material is also considered as being of 'Scraped & stockpiled' consistency. In this example, the proportion of manure to solid storage, lagoon and pasture would be 60.3%, 21.9% and 17.8%, respectively.

If the cows also remain in a compost barn for their dry period, you need to determine the sum of the lactating and non-lactating period. The easiest way to do this would be to calculate the total number of hours per year, subtract the number of hours per year the cow's manure is flushed to a pond/lagoon system and then divide the remaining hours by 24. For example, 24 hours per day x 365 days = 8,760 hours per annum. The cow's flushed manure is 8 hours per day x 300 days = 2,400 hours per year. Subtracting 2,400 from 8,760 = 6,360 hours per annum the manure is in a compost/ scraped & stockpiled consistency. Divide this by 24 hours per day = 265 days. In this example, the time entered for the feedpad is 24 hours per day for 265 days per annum. The proportion of manure will then be proportionally allocated to anaerobic lagoon and solid storage.

In version 5 of ADCC, we assumed that if you selected Yes to pre-treatment of the waste, that 20% of the solids were removed and allocated to scrapped & stockpiled while the remaining 80% continued to the lagoon system. Users can now enter the percentage removed, up to a maximum of 50%. If users select pre-treatment but do not enter a percentage of removal value, ADCC reverts back to the previous default of 20%.

Figure 27 is an example of entering data to determine how the manure is managed when entering your own farm management data. The cows are either moving to/from the dairy or in the dairy for 4 hours per day for 300 days per annum. As the user did not indicate that this manure drain to a paddock or was spread daily from a sump/dispersal system, ADCC assumes all the manure is flushed to a pond/lagoon system. In this example, we also assumed there was some form of pre-treatment (selected from the drop-down list), with a solids-trap in place to collect 25% of the solids. The milkers then spent another 2 hours per day for 150 days per annum on a feedlot, where their manure was periodically scraped and stockpiled. ADCC has calculated that 10.3% of the milkers' manure is managed via a lagoon system (manure from the dairy), 6.8% of their manure is managed as solid storage category, reflecting the 'Scraped & stockpiled option (i.e. solids trapped from the dairy before entering the lagoon plus the manure from the feedlot), while the balance 82.9% of manure was deposited on pastures during grazing (Figure 27). The milker integrated MCF (methane conversion factor) is slightly lower, at 8.5%, compared to the Victorian default of 8.9%, thus illustrating that entering on-farm practices can result in lower emissions compared to selecting the state-based default option.

In some circumstances, heifers might also be retained off paddocks, such as in TMR farms or fed on a feedpad over the summer period when pasture availability is low. In these instances, ADCC also needs to estimate the time these animals are on hard surfaces where their manure is collected. Note here that we are not concerned with heifers being occasionally through yards for routine herd health operations; only if the heifers are retained off paddocks for a significant period throughout the year. In Figure 27, the heifers > 1 yr of age spent 2 hours per day for 150 days on a feedpad, while the heifers and other stock < 1 yr of age only spent 1.5 hours per day for 100 days on the feedpad, while the bulls remained on pasture year-round. Thus, around 2% of their manure was scraped while the remaining 98% was deposited onto pastures while grazing.

Users then can quickly revert back to selecting the '*Default state-based fractions and factors'* to explore the difference in results when using one option compared to the other. Farmers considering using a feedpad to manage supplementary feeding options could use this to understand the implications of changing feeding practices on farm GHG emissions. In the example explored here, when entering on-farm practices, the milker integrated MCF (methane conversion factor) was slightly lower, at 8.5%, compared to the Victorian default of 8.9%. The integrated MCF was slightly higher for all other stock, at

1.02% compared to the default 1%, although this is not obvious when the values are only presented to one decimal point. This exploration illustrates that entering your own data can result in lower emissions compared to relying on using the default state-based option.

Milkers

	Hours per day	Days per annum
Number of hours per day and days per annum a milker spends at the dairy and adjacent yards where the waste is flushed with water	4	300

Percentage of waste that is flushed and then drains to the paddock with no treatment/ removal of solids	0	%
Percentage of waste that is flushed and then spread daily from a sump/dispersal system (with or without removal of solids)	0	%
Balance assumed to be flushed and then enter a pond/lagoon system	100	%

Do you pre-treat the waste prior to spreading daily from a sump system or entering the lagoon (e.g. weeping wall, solids trap, mechanical separator) to remove a proportion of solids?	YES	
If yes, what percentage of the waste is removed via the pre-treatment process?	25	%

	Hours per day	Days per annum
Number of hours per day and days per annum a milker spends on a feedpad, loafing area, or housed	2	150

Select the option which best describes how the majority of this waste from the feedpad or loafing area is best handled	Scraped & stockpiled

All other stock

	Heifers > 1 yr age	Heifers < 1 yr age	Mature bulls	Other stock < 1 yr age	Other stock > 1 yr age
Hours per day on the feedpad or loafing area	2	1.5	0	1.5	0
Days per annum on the feedpad of loafing area	150	100	0	100	0
Percentage of stock class on feedpad	100	100	0	100	0

Select the option which best describes how this waste from the feedpad or loafing area is best handle	Scraped & stockpiled

Percentage waste to each manure system	Anaerobic lagoon	Sump dispersal	Drain to paddock	Solid storage	Pasture	Integrated methane conversion factor	
Milkers	10.3	0.0	0.0	6.8	82.9	8.5	%
All other stock (weighted-average based on number of head in each stock class)	0.0	0.0	0.0	2.3	97.7	1.0	%

Figure 27. A screenshot of a farm where the milking herd spends some time on a feedlot, so have used the option of exploring the farm-specific manure management practices.

5.6. ‘Your Farm’ results explanation

Once all the data is entered, users can view the results when we entered fertiliser based on tonnes of element per annum (Figure 17), estimated trees on farm based on data entered here (Figure 23), and used the default state-based factors and fractions for manure management (Figure 26). Total GHG emissions were 3,569 t CO_2e (Figure 28). However, as there were trees on farm sequestering 29 t CO_2e/annum (shown as -29 t CO_2e/annum to reflect carbon sequestration as opposed to carbon loss), the resultant net emissions were 3,540t CO_2e/annum. Approx. 85.5% of net GHG emissions were allocated to milk production, with the balance 14.5% attributed to meat production (Figure 28). Milk EI was estimated at 0.95 kg CO_2e/kg FPCM or 13.45 kg CO_2e/kg MS, while meat EI was estimated at 3.87 kg CO_2e/kg liveweight (Figure 28). Due to the difficulty of showing the full results section in a single figure, we have broken this table down into subsections, shown in Figures 29 to 31.

		Milking cows	Heifers > 1 yr age	Heifers < 1 yr age	Mature bulls	Other stock < 1 yr age	Other stock > 1 yr age	N fertiliser	Total GHG (tonnes CO_2e/annum)	% of total GHG (exc. C sequestration in trees)	kg CO_2e/kg FPCM (your farm)
Methane (Scope 1):	Enteric fermentation	1,649	182	89	15	91	0		2,026	57%	0.54
	Manure management	301	4	2	0	2	0		309	9%	0.08
Nitrous oxide (Scope 1):	Direct from dung & urine voided onto pastures	96	16	7	1	7	0		127	4%	0.03
	Direct from manure (storage & spread)	22	0	0	0	0	0		22	1%	0.01
	Indirect N waste	104	14	6	1	6	0		131	4%	0.04
	Direct N fertiliser							135	135	4%	0.04
	Indirect N fertiliser							71	71	2%	0.02
Carbon dioxide:	Electricity (Scope 2)								121	3%	0.04
	Electricity (Scope 3)								14	0%	
	Diesel and unleaded petrol (Scope 1)								41	1%	0.01
	Diesel and unleaded petrol (Scope 3)								10	0%	
	Urea and lime/dolomite (Scope 1)								149	4%	0.04
Pre-farm gate embedded (Scope 3)	Grain/ concentrates								140	4%	0.04
	Forages								32	1%	0.01
	Fertilisers								242	7%	0.07
Total GHG emissions		2,171	215	104	18	106	0	206	**3,569**	**t CO_2e/annum**	
% of total GHG emissions (before carbon sequestration is taken into account)		61%	6%	3%	0%	3%	0%	6%			
Carbon sequestration	Tree plantings, with negative figures representing amount of carbon sequestered								-29	**t CO_2e/annum**	
Net GHG emissions									**3,540**	**t CO_2e/annum**	
GHG emissions intensity (kg CO_2e/kg fat and protein corrected milk (FPCM))											**0.95**
GHG emissions intensity (kg CO_2e/kg milksolids)											**13.45**
GHG emissions intensity (kg CO_2e/kg liveweight)											**3.87**
Proportion of net emissions allocated to milk											**85.5%**
Proportion of net emissions allocated to meat											**14.5%**

Figure 28. Screenshot illustrating the results for the whole farm. The results are segmented into subsequent figures for easier reading**.**

Results are presented as total GHG emissions for each stock class, along with direct and indirect N fertiliser emissions. Figure 29 shows the breakdown of emission for the milking herd, mostly CH_4, with enteric fermentation at 1,649 t CO_2e, and manure management at 301 t CO_2e. The milking herd was responsible for 2,171 t CO_2e, equivalent to 61% of total farm GHG emissions. Emissions for the Heifers > 1 yr age were significantly lower, at 215 t CO_2e/annum, representing 6% of total farm GHG emissions.

		Milking Cows	Heifers >1 yr age
Methane (Scope 1):	Enteric fermentation	1,649	182
	Manure management	301	4
Nitrous oxide (Scope 1):	Direct from dung & urine voided onto pastures	96	16
	Direct from manure (storage & spread)	22	0
	Indirect N waste	104	14
	Direct N fertiliser		
	Indirect N fertiliser		
Carbon dioxide:	Electricity (Scope 2)		
	Electricity (Scope 3)		
	Diesel and unleaded petrol (Scope 1)		
	Diesel and unleaded petrol (Scope 3)		
	Urea and Lime/dolomite (Scope 1)		
Pre-farm gate embedded (Scope 3)	Grain/ concentrates		
	Forages		
	Fertilisers		
Total GHG emissions		2,171	215
% of total GHG emissions (before carbon sequestration is taken into account)		61%	6%

Figure 29. Screenshot illustrating the milking cows and heifers > 1 year of age total greenhouse gas emissions.

Users can also see the breakdown across each source. For example, CH_4 from enteric fermentation across the whole herd totalled 2,026 t CO_2e, equivalent to 57% of total farm GHG emissions (Figure 30). The second largest source was CH_4 from manure management, mainly associated with the manure while in effluent ponds, at 309 t CO_2e, equivalent to 9% of total farm GHG emissions. Purchased fertilisers was the third largest source at 7% of total farm GHG emissions, while all other sources ranged between < 1 and 4% of total GHG emissions (Figure 30). Here we can also see that trees were able to sequester 29 t CO_2e/annum (shown as a negative value), decreasing net farm GHG emissions to 3,540 t CO_2e/annum.

		Total GHG (tonnes CO_2e/annum)	% of total GHG (exc. C sequestration in trees)
Methane (Scope 1):	Enteric fermentation	2,026	57%
	Manure management	309	9%
Nitrous oxide (Scope 1):	Direct from dung & urine voided onto pastures	127	4%
	Direct from manure (storage & spread)	22	1%
	Indirect N waste	131	4%
	Direct N fertiliser	135	4%
	Indirect N fertiliser	71	2%
Carbon dioxide:	Electricity (Scope 2)	121	3%
	Electricity (Scope 3)	14	0%
	Diesel and unleaded petrol (Scope 1)	41	1%
	Diesel and unleaded petrol (Scope 3)	10	0%
	Urea and Lime/dolomite (Scope 1)	149	4%
Pre-farm gate embedded (Scope 3)	Grain/ concentrates	140	4%
	Forages	32	1%
	Fertilisers	242	7%
Total GHG emissions		**3,569**	**t CO_2e/annum**
% of total GHG emissions (before carbon sequestration is taken into account)			
Carbon sequestration	Tree plantings, with negative figures representin	-29	**t CO_2e/annum**
Net GHG emissions		**3,540**	**t CO_2e/annum**

Figure 30. Screenshot illustrating the total farm GHG emissions and percentage of total farm greenhouse gas emissions for each source (note most columns have been hidden to illustrate this).

Net GHG emission (i.e. total emissions minus carbon sequestered in trees) are divided by milk production to allow comparison between years or farms. In this example, 85.5% of GHG emissions were attributed to milk production, using an adapted method based on the that described by IDF (2022). Therefore, EI was 0.95 kg CO_2e/kg FPCM or 13.45 kg CO_2e/kg milk, while meat EI was 3.87 kg CO_2e/kg liveweight (Figure 31). If users wanted to compare their EIs to historical data, where net emissions were fully allocated to milk production, divide milk EI by the % allocated to milk. For example, 0.92 kg CO_2e/kg FPCM divided by 85% allocated to milk equals an EI of ~ 1.08 kg CO_2e/kg FPCM.

GHG emissions intensity (kg CO_2e/kg fat and protein corrected milk (FPCM))	0.95
GHG emissions intensity (kg CO_2e/kg milksolids)	13.45
GHG emissions intensity (kg CO_2e/kg liveweight)	3.87
Proportion of net emissions allocated to milk	85.5%
Proportion of net emissions allocated to meat	14.5%

Figure 31. Screenshot illustrating the emissions intensity of milk and meat production when a proportion of emissions are allocated to meat (note most columns and rows have been hidden to illustrate this).

Results are also presented graphically, detailing the percentage of emissions for each source, along with carbon sequestered in trees for the farm being assessed and for a typical farm, South West Victoria in this example (Figure 32). In the example below, the graphs have been presented vertically here due to the size of the graphs. The proportion of emissions from each source for this farm is similar to the south-west Victorian average. However, when compared to all other medium grain feeding farms, this farm has a lower proportion of enteric CH_4 emissions while fertiliser-derived N_2O and CO_2 emissions (i.e. direct and indirect N_2O emissions, CO_2 from urea and lime plus Scope 3 emissions for fertilisers), are higher than the average medium grain feeding farm (Figure 32; see Appendix 4 for the typical/industry average values as these are not presented in the Results table).

If EI for the farm is outside an expected range of between 0.6 and 1.2 kg CO_2e/kg FPCM or between 8 and 18 kg CO_2e/kg milksolids, check data entry to ascertain if there are any noticeable data entry errors. If the farm has large areas of trees on farm, net EIs could be lower than this range. Greater allocation of emissions to meat will further reduce milk EI. However, the level of reduction cannot be indicated here as some farms might only have 10-15% of emissions allocated to meat (i.e. small amount of meat leaving the farm, for example when all non-replacement animals are sold either at one week of age or post-weaning) while others may have 40-50% of emissions allocated to meat (i.e. retain all non-replacement animals to fatten before selling to processors).

Analysing the graphs may also help with ascertaining if there are any data entry errors. For example, if your farm's energy consumption was 40% of net GHG emissions, this is significantly different to the typical farm, averaging 5-10%. Therefore, check data entry for electricity and fuel consumption. Minor errors in data entry are more difficult to ascertain as the result might still fall within typical ranges.

We have provided typical averages based on several years of data from Dairy Australia's DairyBase program, using the Dairy Farm Monitor Project (DFMP) and Queensland Dairy Accounting Scheme (QDAS) datasets (approx. 1,000 datasets from 2019-20 to 2023-24 inclusive). The user needs to select their region, at the top of the worksheet, so ADCC can populate the typical averages graph. Alternatively, users can compare their results to other regions, the Australia-wide average or level of grain feeding. Previous versions of ADCC presented results as % of total farm emissions. This is still presented for 'Your Farm', as a pie chart in the 'Data Summary' tab. Now we are presenting the results for 'Your Farm' and the typical average farm as emissions intensity values (Figure 32).

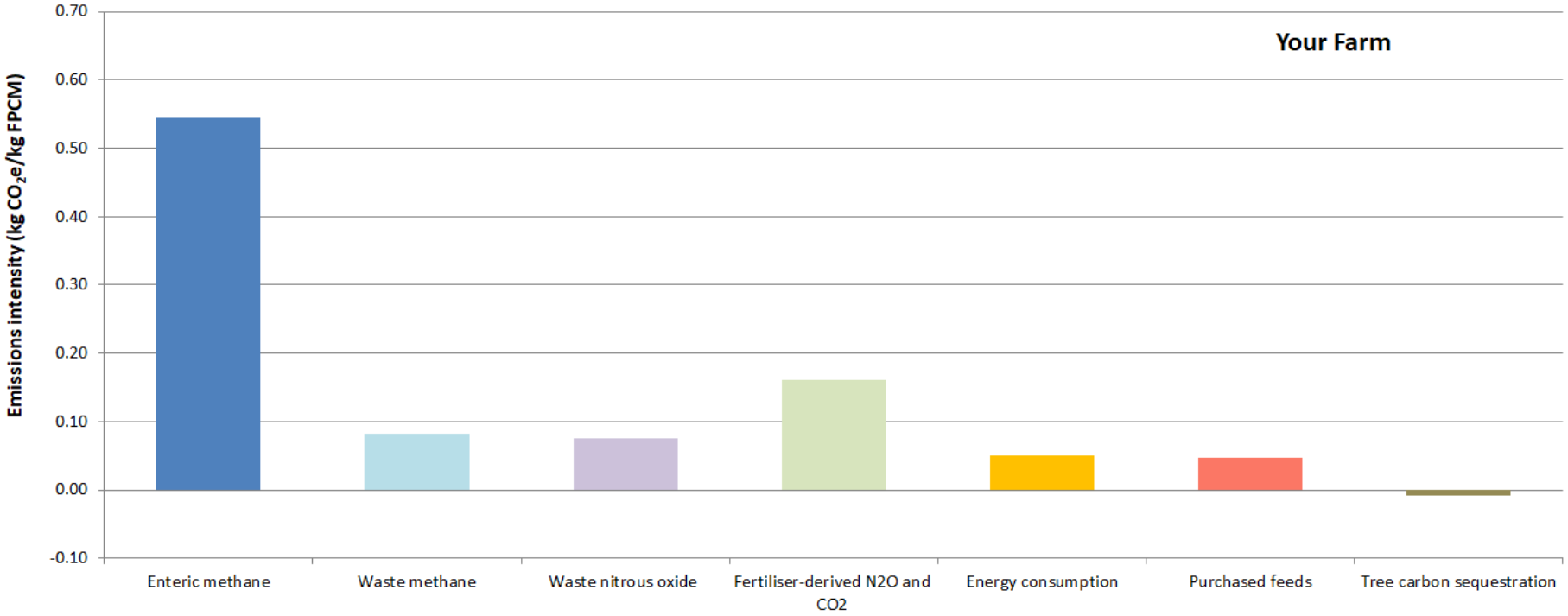


Figure 32. Screenshot of the percentage of the total greenhouse gas emissions and carbon sequestered in trees for the farm being assessed compared to the average of all medium-grain feeding farms (see next page).

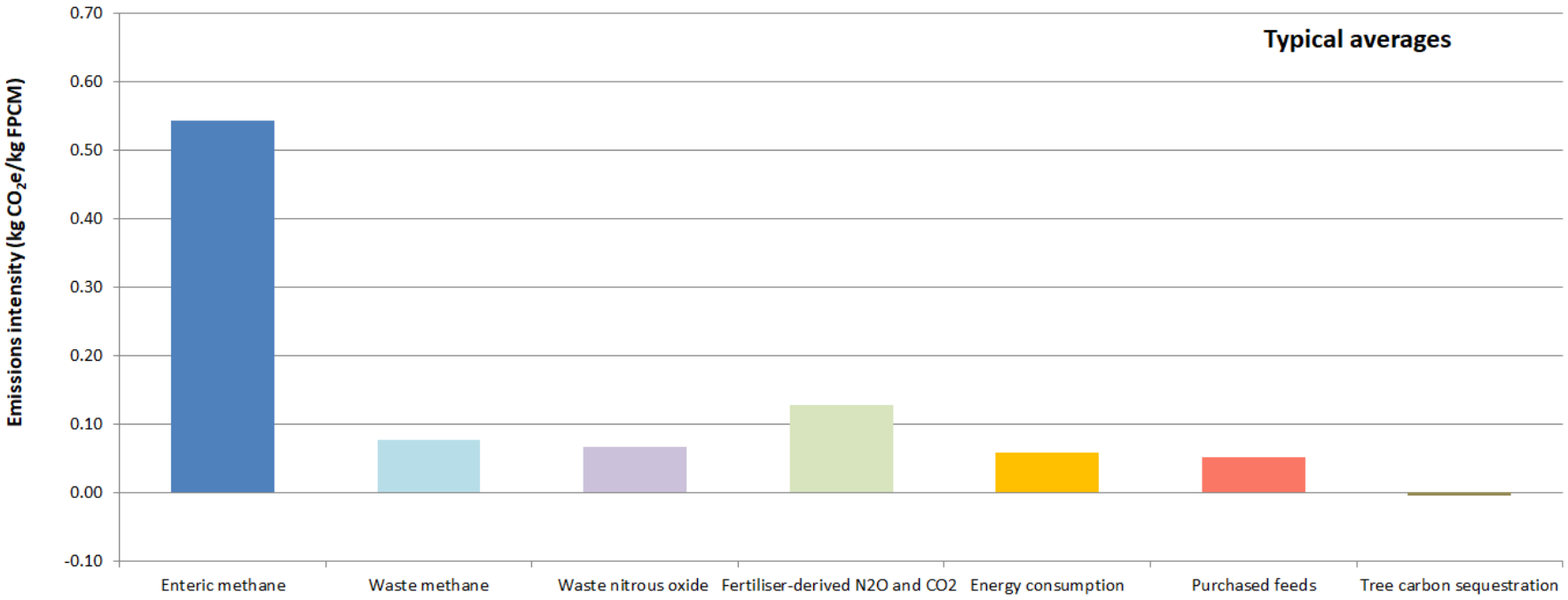


Figure 32 cont. Screenshot of the percentage of the total greenhouse gas emissions and carbon sequestered in trees for the farm being assessed (see previous page) compared to the average of all medium-grain feeding farms.

Figure 33 illustrates typical average emissions intensity for each source of emissions (kg CO_2e/ kg FPCM), along with the net emissions intensities (kg CO_2e/ kg FPCM, kg CO_2e/ kg MS and kg CO_2e/kg LW) and proportion of emissions attributed to milk and meat production. These values are also included in Appendix 4. In this example, milk emissions intensity, both on a per kg FPCM and per kg MS, is higher for the 'Your Farm' compared to the industry comparison due to higher emissions from electricity and fertilisers. The 'Your Farm' system has more emissions allocated to meat thus diluting meat production to achieve a lower meat emissions intensity.

We have also incorporated a 'Data Summary' tab which contains the main results and includes a pie chart illustrating the proportion of net farm emissions and tree carbon sequestration, as a negative value (Figure 33). This is formatted to be able to be printed off as a single page (Figure 34).

kg CO_2e/kg FPCM (your farm)	kg CO_2e/kg FPCM (industry comparison)	Source of emissions
0.54	0.55	Enteric fermentation
0.08	0.08	Manure management
0.03	0.03	Direct from dung & urine voided onto pastures
0.01	0.01	Direct from manure (storage & spread)
0.04	0.03	Indirect N waste
0.04	0.03	Direct N fertiliser
0.02	0.01	Indirect N fertiliser
0.04	0.02	Electricity (Scope 2 & 3)
0.01	0.02	Diesel and unleaded petrol (Scope 1 & 3)
0.04	0.01	Urea and Lime/dolomite
0.04	0.04	Grain/ concentrates
0.01	0.01	Forages
0.07	0.04	Fertilisers
0.95	**0.89**	kg CO_2e/kg FPCM (post carbon sequestration)
13.45	**12.35**	kg CO_2e/kg milksolids (post-carbon sequestration)
3.87	**4.78**	kg CO_2e/kg liveweight meat (post-carbon sequestration)
85.5%	**87.5%**	Proportion of emissions allocated to milk
14.5%	**12.5%**	Proportion of emissions allocated to meat

Figure 33. Screenshot showing the comparison of emission intensities for the 'Your Farm' compared to the industry comparison, which is medium grin feeding in this example. Several rows have been hidden to remove blank cells.

The 'Data Summary' tab also contains a new graph, grouping emissions into four main areas; livestock, effluent/manure, fertiliser and energy and fuel, showing how much your farm values alter from the industry average (not shown here, but later when we explore the Profitable Emissions Action Plan (section 7).

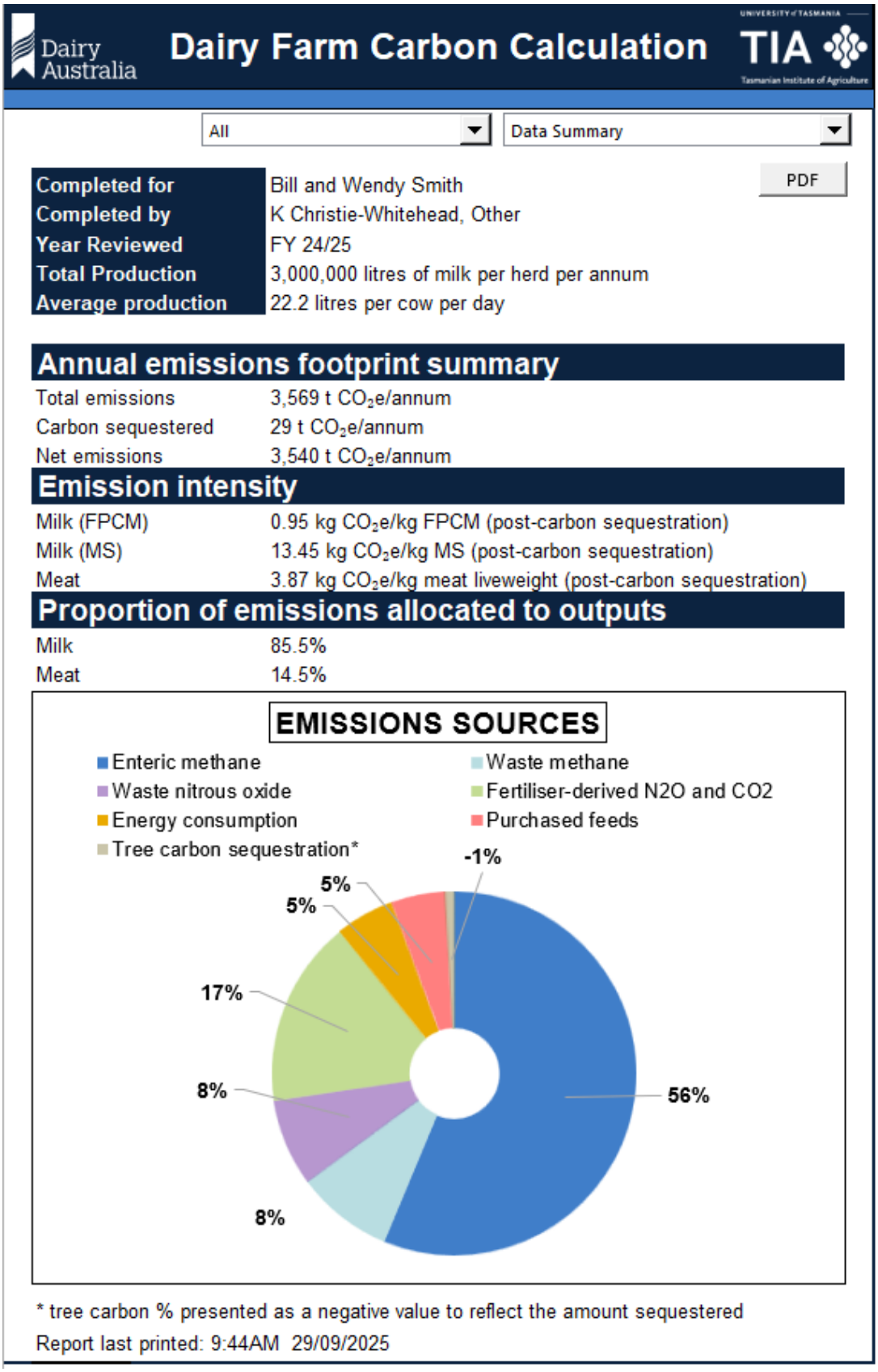


Figure 34. Screenshot of the 'Data Summary' tab with the key results presented in a single, printable page.

5.7. Previous methodology comparison

Over time, as new knowledge from scientific research emerges, the NGGI methodology is updated. Examples of this have been changes to the Australian enteric CH_4 equation or changes to global GWPs for CH_4 and N_2O. The Australian NGGI methodology was developed in 1990, and since then there has been two major updates, in 2017 (ADCC version 4), and more recently in 2022 (ADCC version 5.1 and 5.2), 2024 (ADCC version 5.3) and then in 2025 (ADCC version 5.4 and then 6.1 (current version))). Within ADCC, we have retained these older methodologies, facilitating users to compare the same farm input data across all three NGGI methodologies. By entering data into the 'Your Farm' tab, this populates and estimates the 1990, 2017 and 2022 methodology comparisons. A more recent change in 2025 resulted in slight changes in diesel and electricity emissions. However, given these are a small proportion of emissions, we have not created a 2024 methodology comparison. For this 'Your Farm' example, emissions remained the same when reported to the level of accuracy shown here (whole numbers for net emissions and 1-2 decimal points for emissions intensities etc).

We examined the impact of methodology change on net farm GHG emissions using the example farm used predominantly throughout this manual. For the 1990 and 2015 methodology we retained using the old method of electricity assessments by implementing brown coal as the source of electricity. This was only updated to the state-based with the 2022 methodology comparison.

In 1990, the 'Your Farm''s GHG emissions, after taking into account tree carbon sequestration, was 3,216 t CO_2e/annum, increasing to 3,266 t CO_2e/annum with the 2017 methodology, thus both methodologies are lower than the current results of 3,540 t CO_2e/annum with the 2025 methodology. Emissions intensity followed a similar pattern as net farm emissions were divided by the same amount of milk production. However, the 2022 methodology resulted in a net farm GHG emission of 3,584 t CO_2e/annum which is 44.7 t CO_2e/annum higher than the current 2024 methodology results, thus a 1.2% decline in net farm GHG emissions, shown as green boxes to illustrate the new methodology is an improvement for this farm example (Figure 35).

The biggest contributor to the rise in net GHG emissions over time has been the increase in GWP of CH_4. In 1990, the NGGI methodology adopted the GWP of 21 (based on the IPCC's Second Assessment Report (SAR)), increasing to 25 in 2017 (based on the IPCC's Fourth Acceptable Report (AR4)) and further again in 2022 to 28 (based on IPCC's Fifth Acceptable Report (AR5)) (Myhre *et al.* 2013). At the same time, the GWP for N_2O has declined from 310 to 298, and now to 265 (Myhre *et al.* 2013). Inclusion of CO_2 from urea and lime have been included for the first time with the 2022 methodology. Other emission factors have also altered over time, although these changes have had minimal impact on total GHG emissions. Given that the largest source of GHG emissions is enteric CH_4, any change in the GWP can substantially impact net GHG emissions.

When comparing results, it is important to understand which methodology is being used, especially the GWPs, and whether a proportion of emissions have been allocated to meat. If so, which allocation method (i.e. mass, economic, systems expansion, or energy as implemented in ADCC; see Appendix 3) was used to estimate GHG emissions. Otherwise, you may be comparing 1990 results with no meat GHG allocation with 2022 results with a meat GHG allocation.

Net GHG emissions with 2022 methodology	**3,559**	**t CO_2e/annum**
Net GHG emissions with current 2025 methodology	3,540	**t CO_2e/annum**
Change in GHG emissions with the new 2025 NGGI methodology	**19.3**	**t CO_2e/annum**
% change in GHG emissions with the new 2025 NGGI methodology	**0.5**	**%**

Figure 35. Screenshot of the comparison of the net farm GHG emissions with the 2022 methodology vs the 2025 methodology. In this example, the current methodology results are an improvement in net farm GHG emissions, hence green cells. If the current methodology resulted in an increase in net farm GHG emissions, the cells would be red in colour and contain negative values to reinforce increase in net farm GHG emissions as a consequence of methodology change.

5.8. Importing a DairyBase farm system file into ADCC

A new feature of ADCC is the ability to import DairyBase farm system files. This saves users time in needing to re-enter data into ADCC to explore the intervention options within COST (see section 8). In the top right corner of the 'Your Farm' tab, there is an Import from DairyBase button (Figure 36), along with hyperlinks to other parts of ADCC to explain how to download and import a DairyBase farm file and help with enabling macros. These instructions are also included in the manual in x 1 and 2. Briefly, when clicking on the import from DairyBase button, you will be asked if you wish to continue with importing the DairyBase file. If yes, then you then need to locate the already downloaded DairyBase file, click ok and then ADCC will import the file (may take up to a minute). We have also taken the opportunity to include a clear input cells button so that you can remove all data entry if required.

Figure 36. Screenshot of the top right corner of the 'Your Farm' tab showing the button to clear input cells and to import a DairyBase farm file along with hyperlinks to the 'Introduction' tab to explain how to import a DairyBase file and help if you can run the macros.

We do not envisage any major differences in carbon footprint results between DairyBase and ADCC. However, there may be a very small difference (1-3%) due to how each calculator determines aspects such as stock numbers. The biggest difference relates to DairyBase only having a single 'Other livestock' class. When importing data into ADCC, these Other livestock are copied into the 'Other stock < 1 yr age' category where they have lower CH_4 and N_2O emission factors for the first 84 days of life. After this period, the emission factors revert to the same method as per the rest of the stock in DairyBase. Therefore if you DairyBase herd has a large number of Other Livestock, the difference in results between the two calculators will increase, with the standalone version of ADCC giving you the more accurate assessment. If there are major discrepancies, check that the DairyBase file you have imported is the same as the one you are reviewing in DairyBase.

If you receive an error message when importing a DairyBase file (for example Figure 37), this means that there has been an issue with importing data. In this example, we had two errors related to electricity. This may occur with older DairyBase farm files as the naming of data entry cells within DairyBase has altered over time, resulting in ADCC not recognising 'ElectricityPurchased' and 'ElectricityPurchasedRenewablePercent'. If this occurs, click OK and then review the data entry cells in ADCC related to the error messages. You may need to enter missing data.

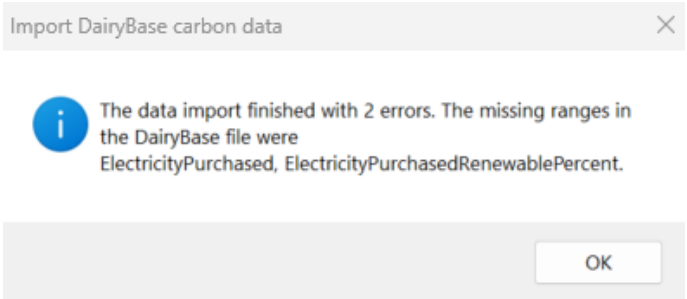


Figure 37. Example of an error message when importing an older DairyBase farm file.

A new feature we have also added into ADCC is a boxed area to the right of the data entry area for users to enter comments, work out data for entry into the relevant cells etc. One example might be how you determined milking herd size so that you can repeat this same method for subsequent years. Any information in this box will be deleted if the user selects the Clear input cells option in the top right hand cornier of the tab.

6. Benchmarking of DairyBase results

Benchmarking your farm data can be an effective way of reviewing how your farm's GHG emissions are tracking. This could be comparing results for your own farm over several years, or between your farm and others in your region. This section of the manual contains a range of analyses of the GHG emissions estimates from within Dairy Australia's DairyBase program (https://www.dairyaustralia.com.au/farm-business/dairybase). These are datasets from the Dairy Farm Monitor Project (DFPM) for the years 2006/07 to 2022/23 inclusive. While DairyBase contains over 3,000 DFMP datasets, this review was restricted to the 2,141 datasets which contained a complete list of realistic input data. For example, datasets that selected state-based factors but with missing or zero electricity consumption and/or diesel consumption data were excluded from the analysis (e.g. some of the earlier years for Tasmania, while Queensland data was only included from 2022/23 although their electricity usage values for that year do appear to be quite low for their corresponding herd size). Datasets where they had selected 100% renewable energy was included as the emissions from this would remain 0 t CO_2e/annum. Some farms with 100% renewable energy had entered a single litre of diesel consumption (only Tasmania). This was perceived as being unrealistic, and thus would remove this state's data for a couple of years so these datasets were allowed to remain as being indicative of a full dataset. We have also started to tighten up on contractor fuel usage which should be included in the estimates, with the results of this not likely to being until the 2023/24 year. In addition, datasets with N fertiliser inputs which appeared to be total tonnes, as opposed to kg N/ha, were also excluded (most of the early years for QLD). With the upgrade of DairyBase with new estimates for carbon stored in tree vegetation, the legacy data in DairyBase data did not include the age of tree plantings as well as a simplification of the tree species present on farm (see *Step Eight* in section 5.5). Therefore, estimating carbon sequestration in trees has only need accurate for the last several years.

Figure 38 illustrates the number datasets for each region/state that met the criteria of suitability as mentioned above. The DFMP commenced in the 2006/07 financial year in the three dairying regions of Victoria. New South Wales and South Australia commenced in 2012/13 (although there was a single dataset for Nth NSW for 2011/12 included), with Tasmania and Western Australia one year later in 2013/14 and finally Queensland in 2022/23. As shown in Figure 38, there was a significant decline in the number of datasets in 2016/17. A review undertaken previously had more farms present with full datasets for 2016/17. However, this assessment did not retain this electricity and/or fuel data and thus was excluded from all other assessments, unless listed otherwise.

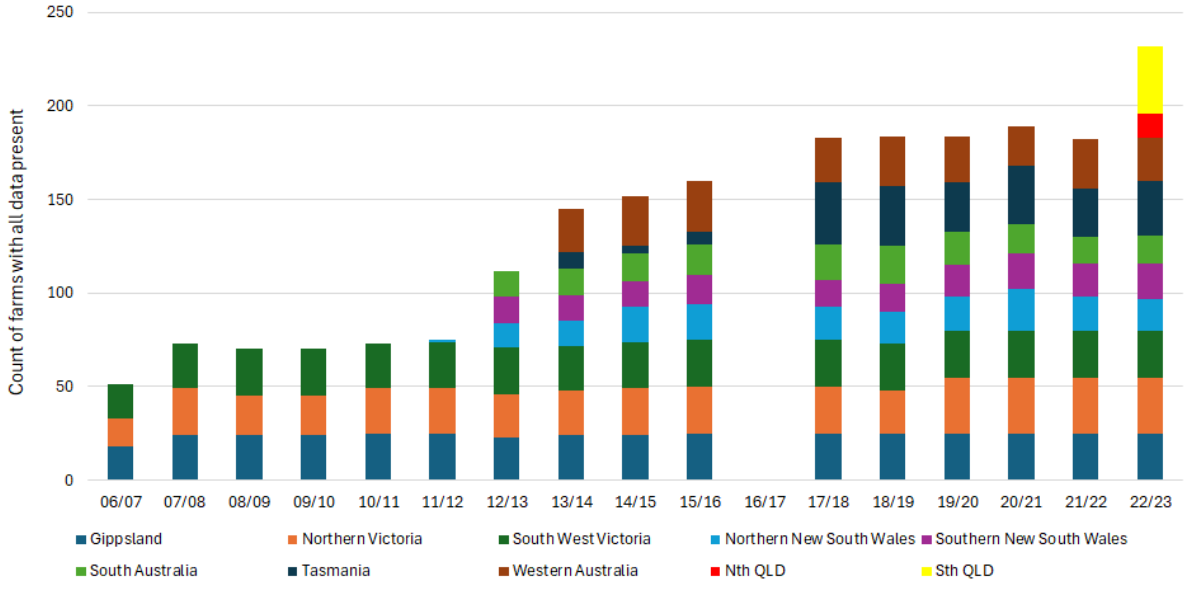


Figure 38. Number of Dairy Farm Monitor Project datasets for each year from each dairy region where all the data was included in DairyBase (n=2,141). Note the year reflects the second half of the financial year, so 2007 reflects 2006/07.

Total farm milk production was assessed against net farm GHG emissions attributed to milk production (i.e. removal of GHG emissions attributed to meat production deducted from net farm GHG emissions), using a linear regression analysis (y=Bx+a). The slope of the regression (B value in the regression equation) was 0.9046, with a residual 'a' value of -2.5935 (Figure 39). The co-efficient of determination (R^2; where an R^2 of 1 indicates the regression prediction perfectly fits the data) was 0.9658, thus indicating that this regression equation is an excellent predictor of net GHG emissions from milk production across such a large dataset (Figure 39). Therefore, we can have high confidence that if a farm's milk production was 5,000 t FPCM/annum, their approx. GHG emissions, rounding up the B value and discarding the 'a' value, could be estimated as 5,000 x 0.9046 = ~ 4,520 t CO_2e/annum.

However, not every farm data sits on this linear regression line, thus there can be some variation away from this linear regression equation. The orange dot farm datasets in Figure 39 (n=91) represent datasets where the standard residual is > 2, indicating the difference between their estimated GHG emissions, based on DairyBase, and that predicted, as derived by the regression equation, was more than 2 standard deviations away from the Dairybase estimated-mean. Orange dots that sit above the blue regressions line indicate their GHG emissions estimated in DairyBase is greater than predicted from annual milk production. This could potentially indication inefficiencies on farm (i.e. lower conversion of N fertiliser into grass and then milk). Alternatively, less meat was sold than expected, resulting in DairyBase attributing a greater proportion of GHG emissions to milk production. Conversely, orange dots below the regression line indicate their GHG emission estimate in DairyBase was lower than predicted based on milk production. This could be a result of increased efficiency on farm and/or producing more meat than expected, thus DairyBase directed more GHG emissions towards meat production (Figure 39).

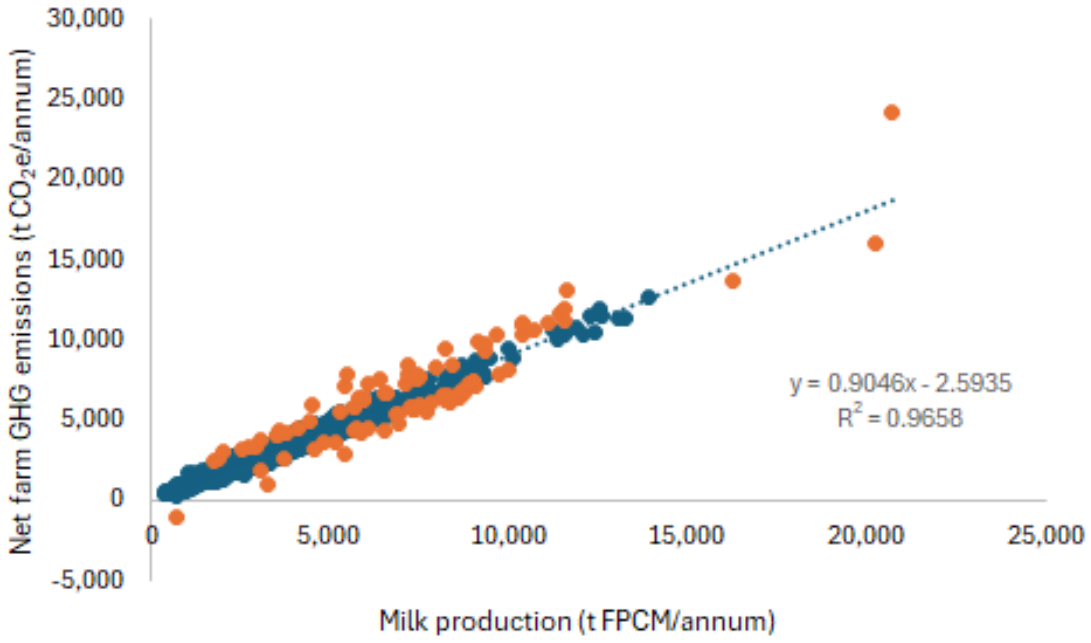


Figure 39. Linear regression relationship between milk production (t FPCM/annum) and net GHG emissions (t CO_2e/annum). The orange dots indicate farm datasets with a standard residual > 2, indicative of outlier results relative to the linear regression relationship.

The previous manual discussed the EI of milk production prior to allocating a proportion of GHG emissions to meat production. However, as this is no longer current practice, nor reported via the ADCC tools, we have not presented those results here. However, we are presenting a comparison of the EIs from the previous methodology, as per that presented in the previous manual (ADCC version 5.0) (Table 2) with that of the current methodology (Table 3). This will help to show how the changes in methodology has impacted milk and meat EI for the financial years 2006-07 through 2020-21 plus the updated data for 2021-2022 and 2022-23 years.

The long-term (2006-07 to 2022-23), Australia-wide milk EI has declined slightly, from 0.93 kg CO_2e/kg FPCM (Table 2) to now be 0.91 kg CO_2e/kg FPCM (Table 3). In contrast, meat EI has increased from ~ 4.4 kg CO_2e/kg LW to 4.7 kg CO_2e/kg LW (Table 3). Previously, we had allocated the GHG emissions from all grains/concentrates/pellets to the milking enterprise. However, after a long discussion with the industry, especially those raising larger numbers of stock for the meat enterprise where some grain/concentrates are fed, we now allocate based on where the supplement is fed, either the milking platform (allocated to the milk enterprise) vs the support block (allocated to the meat enterprise). This alone may have resulted in these changes in meat EI. As the number of full datasets for the 2016/17 was minimal, we have removed this data from the two tables below.

In the last year (2022-23), within the DFMP, data collection around manure management has moved away from the state-based factors, towards farm-specific manure management data. For farms that have the milking cow spending minimal time at the dairy (i.e. < 3-4 hrs/day), reverting to the user-defined manure management fractions has likely reduced waste manure emission. In contrast, farms where cows spend longer at the dairy and/or on a feedpad or housed, the user-defined factors will have increased waste manure emissions. For most states, the current methodology EI increased in 2022/23, compared to 2021/22 (Table 3, the only clear exception was in Tasmania, where the state-average EI declined, although the result for 2022/23 was similar to years before 2021/22 (Table 3). We will require several more years of user-defined manure management to ascertain a longer-term trend. What is also clear is that milk EIs in the baseline year of 2015/16, as per the dairy industry's Sustainability Framework, were lower than current. However, this too may be an artifact of the method of estimating waste manure emissions as opposed to any other on-farm practice change.

We are also starting to see greater inclusion of tree carbon sequestration within the data collection phase and with the changeover in method of estimating tree carbon sequestration in the last year, the results are coming into the net farm GHG emissions. This is very evident with Nth NSW in 2022-23, with greater tree carbon data entry resulting in a substantial decline in regional EIs, from 1.00 kg CO_2e/kg FPCM in 2021/22 to now 0.79 kg CO_2e/kg FPCM in 2022/23 (Table 3).

Table 2. Previous methodology mean regional and national milk emissions intensity (kg CO_2e/kg FPCM), and meat emissions intensity (kg CO_2e/kg liveweight), when allocating a proportion of GHG emissions to meat production. FY 2007 reflects the 2006-07 financial year. Note due to smaller number of datasets in 2016-17 having a full dataset (most farms missing electricity and/or diesel consumption and thus emissions from these), we decided to remove this year's data from the table.

Year	SE VIC	Nth VIC	SW VIC	Nth NSW	Sth NSW	SA	TAS	WA	Aus wide	Meat EI
FY 2007	1.00	1.02	0.92						0.98	4.7
FY 2008	0.96	0.91	0.97						0.95	4.5
FY 2009	0.93	0.91	0.92						0.92	4.4
FY 2010	0.96	0.93	0.91						0.93	4.4
FY 2011	0.91	0.90	0.94						0.91	4.4
FY 2012	0.91	0.90	0.93	1.04					0.92	4.4
FY 2013	0.97	0.90	0.93	1.05	0.93	0.89			0.94	4.4
FY 2014	0.94	0.89	0.95	1.07	0.94	0.94	0.91	0.95	0.95	4.4
FY 2015	0.93	0.89	0.93	1.05	0.91	0.87	1.02	0.95	0.94	4.4
FY 2016	0.95	0.90	0.93	1.04	0.91	0.88	0.87	0.92	0.93	4.3
FY 2017										
FY 2018	0.94	0.90	0.97	1.06	0.95	0.88	0.88	0.94	0.93	4.4
FY 2019	0.96	0.91	0.99	1.06	0.98	0.88	0.84	0.92	0.95	4.4
FY 2020	0.93	0.88	0.95	1.04	0.96	0.89	0.85	0.94	0.93	4.3
FY 2021	0.91	0.88	0.92	1.01	0.93	0.85	0.85	0.91	0.91	4.2
Average	0.94	0.90	0.94	1.04	0.94	0.88	0.87	0.93	0.93	4.4

Table 3. Current methodology mean regional and national milk emissions intensity (kg CO_2e/kg FPCM), and meat emissions intensity (kg CO_2e/kg liveweight), when allocating a proportion of GHG emissions to meat production. FY 2007 reflects the 2006-07 financial year. Note due to smaller number of datasets in 2016-17 having a full dataset (most farms missing electricity and/or diesel consumption and thus emissions from these), we decided to remove this year's data from the table.

Year	SE VIC	Nth VIC	SW VIC	Nth NSW	Sth NSW	SA	TAS	WA	Nth QLD	Sth QLD	Aus wide	Meat EI
FY 2007	0.98	1.00	0.91								0.96	4.9
FY 2008	0.95	0.91	0.97								0.94	4.7
FY 2009	0.91	0.89	0.92								0.91	4.5
FY 2010	0.93	0.90	0.90								0.91	4.6
FY 2011	0.90	0.88	0.92								0.90	4.6
FY 2012	0.89	0.88	0.91	1.01							0.90	4.6
FY 2013	0.94	0.88	0.91	1.01	0.91	0.82					0.91	4.6
FY 2014	0.93	0.87	0.94	1.03	0.91	0.86	0.91	0.94			0.92	4.7
FY 2015	0.92	0.87	0.92	1.02	0.88	0.80	1.03	0.94			0.91	4.6
FY 2016	0.94	0.88	0.92	1.01	0.88	0.81	0.87	0.92			0.91	4.6
FY 2017												
FY 2018	0.91	0.85	0.93	1.00	0.90	0.82	0.87	0.92			0.90	4.6
FY 2019	0.94	0.89	0.98	1.02	0.94	0.81	0.87	0.91			0.92	4.5
FY 2020	0.91	0.86	0.95	1.00	0.92	0.83	0.86	0.93			0.90	4.4
FY 2021	0.89	0.86	0.91	0.99	0.90	0.79	0.86	0.91			0.89	4.7
FY 2022	0.87	0.84	0.91	1.00	0.90	0.81	0.89	0.93			0.90	5.2
FY 2023	0.90	0.90	0.92	0.79	0.94	1.04	0.85	0.93	1.04	0.98	0.95	4.9
Average	**0.92**	**0.88**	**0.93**	**0.99**	**0.91**	**0.82**	**0.87**	**0.92**	**1.04**	**0.98**	**0.91**	**4.7**

Milk EIs varied from < 0.75 kg CO_2e/kg FPCM through to > 1.15 kg CO_2e /kg FPCM, with three-quarters of farms within the 0.80 to 1.0 kg CO_2e /kg FPCM range (in the 0.85, 0.9 and 0.95 columns in Figure 40). Meat EIs varied from < 3.6 kg CO_2e /kg LW through to > 6.3 kg CO_2e /kg LW, with three quarters of farms within the 3.9 to 4.8 kg CO_2e /kg LW range (Figure 41).

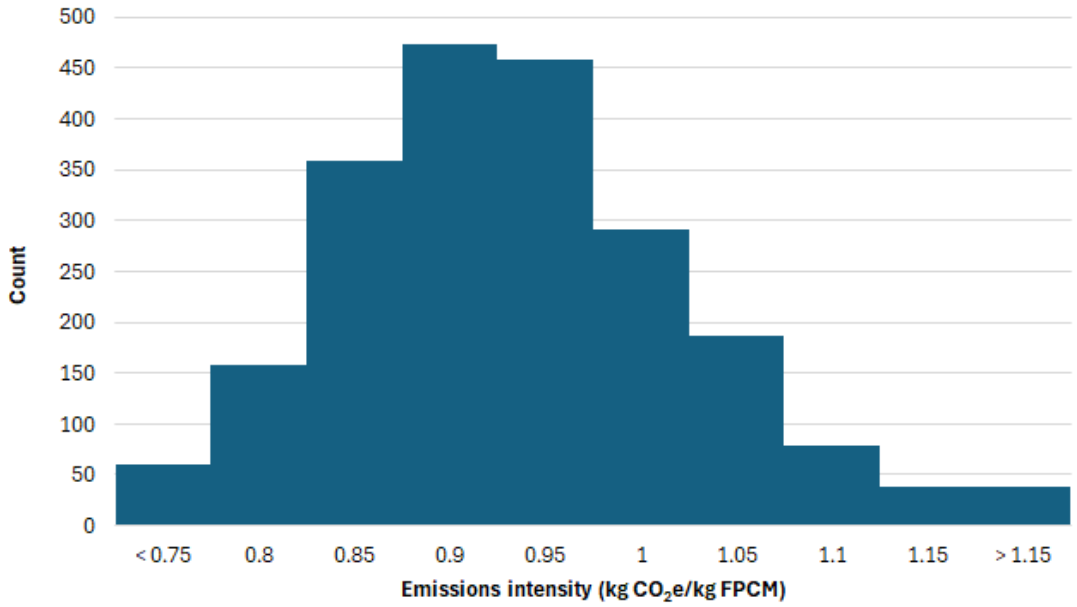


Figure 40. Frequency of emissions intensity of milk production across the 2,141 datasets once a proportion of GHG is allocated to meat production. EIs broken down into 0.05 kg CO_2e/kg FPCM increments where the number listed for each column is the upper limit such that 0.9 reflects the number of datasets with an EI between 0.85 and 0.90 kg CO_2e/kg FPCM.

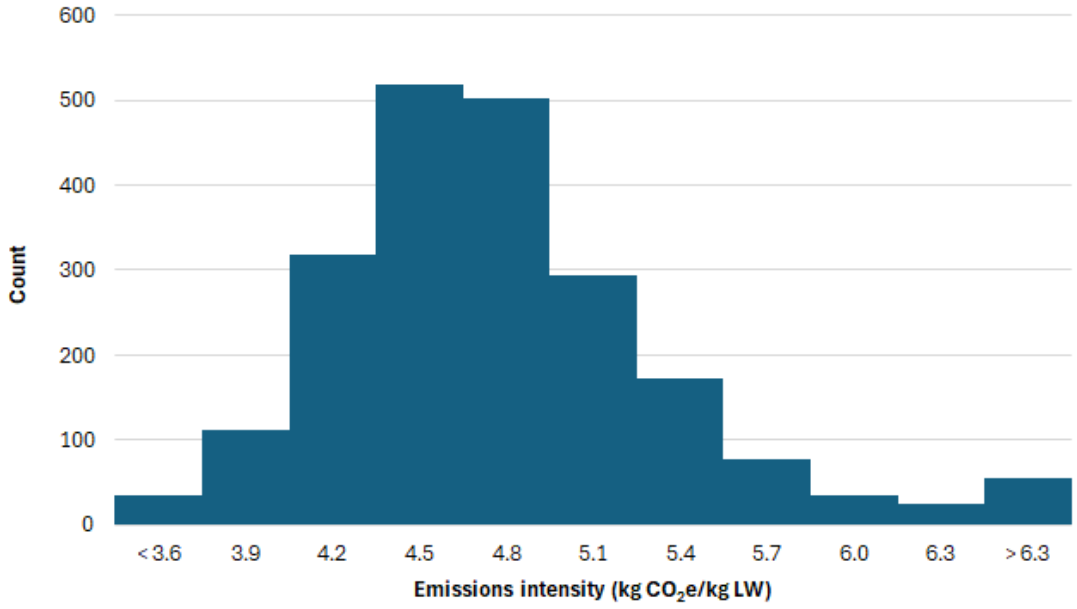


Figure 41. Frequency of emissions intensity of meat production (kg CO_2e/kg liveweight sold) across the 2,141 datasets. EIs broken down into 0.3 kg CO_2e/kg liveweight increments where the number listed for each column is the upper limit such that 3.90 reflects the number of datasets with an EI between 3.6 and 3.9 kg CO_2e/kg liveweight.

While there was a general trend between milk and meat EIs, the low R^2 of the regression equation illustrates only a small correlation. For example, there was many farms with milk EIs lower than the overall dataset average of 0.91 kg CO_2e/kg FPCM but with meat EIs greater than the overall average of 4.7 kg CO_2e/kg LW (red square in Figure 42).

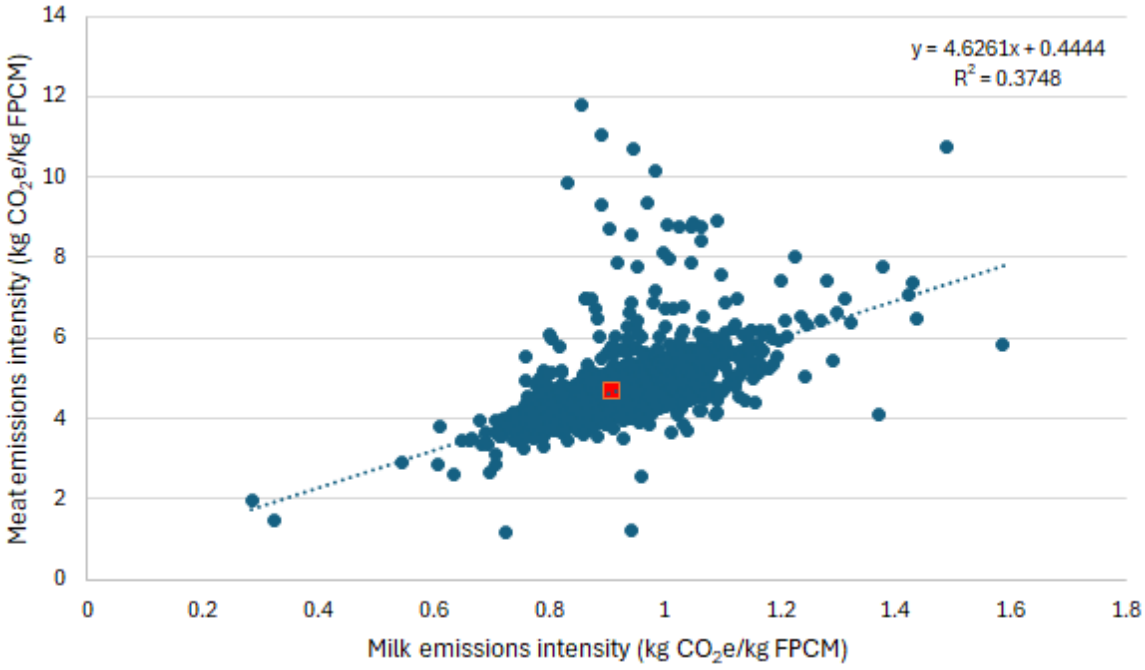


Figure 42. Linear regressions relationship between milk and meat EIs across the 2,141 full datasets from 2006/07 to 2022/23. The red square illustrates the overall milk and meat emission intensity values.

Figure 43 illustrates the proportion of emissions from each source, excluding any sequestration in tree carbon reducing farm GHG emissions as dividing each source by net farm emissions where there is a large insetting of on-farm emissions with tree carbon sequestration could result in a negative proportion (see latter for the effect of trees on farm GHG emissions). Enteric CH_4 was the biggest source of emissions, averaging 62% across the whole dataset, but varying between 37 and 77%. Waste CH_4 was the second highest, averaging 9% (range 1-48%). All other sources averaged < 5%, although individual farms could have greater emissions from a particular source. For example, CO_2 emissions from electricity averaged 3%, yet several farms had electricity emissions > 10% (Figure 43). With the collection and incorporation of on-farm management of stock for manure management, we are beginning to see some datasets with high waste CH_4 source (~ 38-48% in Figure 43). Both of those farms appears to be a total mixed ration where all cows and young stock are housed year round with a substantial amount of their manure stored in pond/lagoon systems and thus, given the high CH_4 factors for this system, waste CH_4 emissions are high.

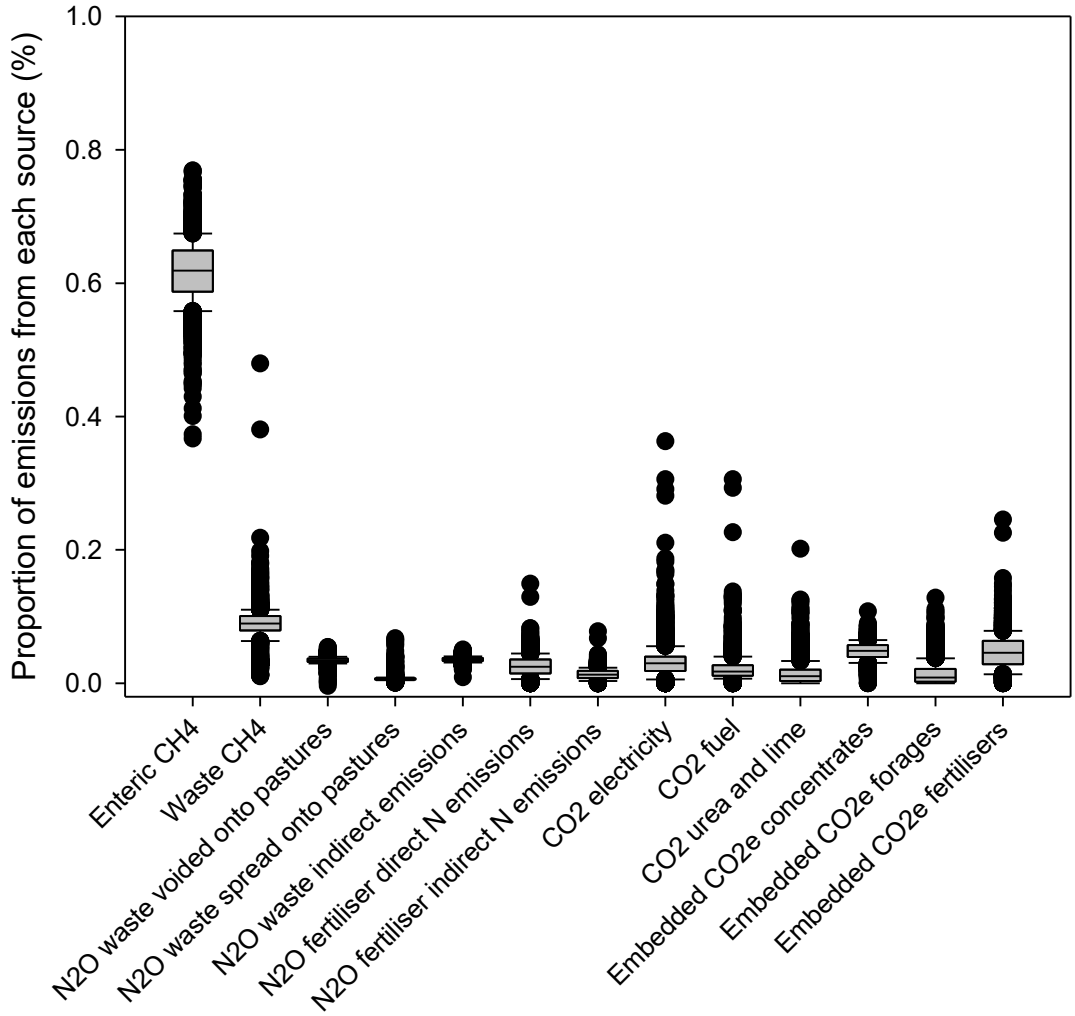


Figure 43. Proportion of GHG emissions from each source for the 2,141 farm datasets. The boxes represents the 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, dots represent outliers, and solid lines in the boxes represent the medians.

A new benchmark presented here is emissions intensity (kg CO_2e/kg FPCM) for each source of on-farm emissions (again, discounting any insetting via on-farm carbon sequestration in trees). Average enteric CH_4 emissions intensity was 0.56 kg CO_2e/kg FPCM, varying between 0.44 and 0.92 kg CO_2e/kg FPCM (Figure 44). Mean waste CH_4 emissions intensity was 0.08 kg CO_2e/kg FPCM, but as highlighted above with some very high proportion of emissions associated to CH_4 waste, emissions intensity could be as high as 0.63 kg CO_2e/kg FPCM (Figure 44).

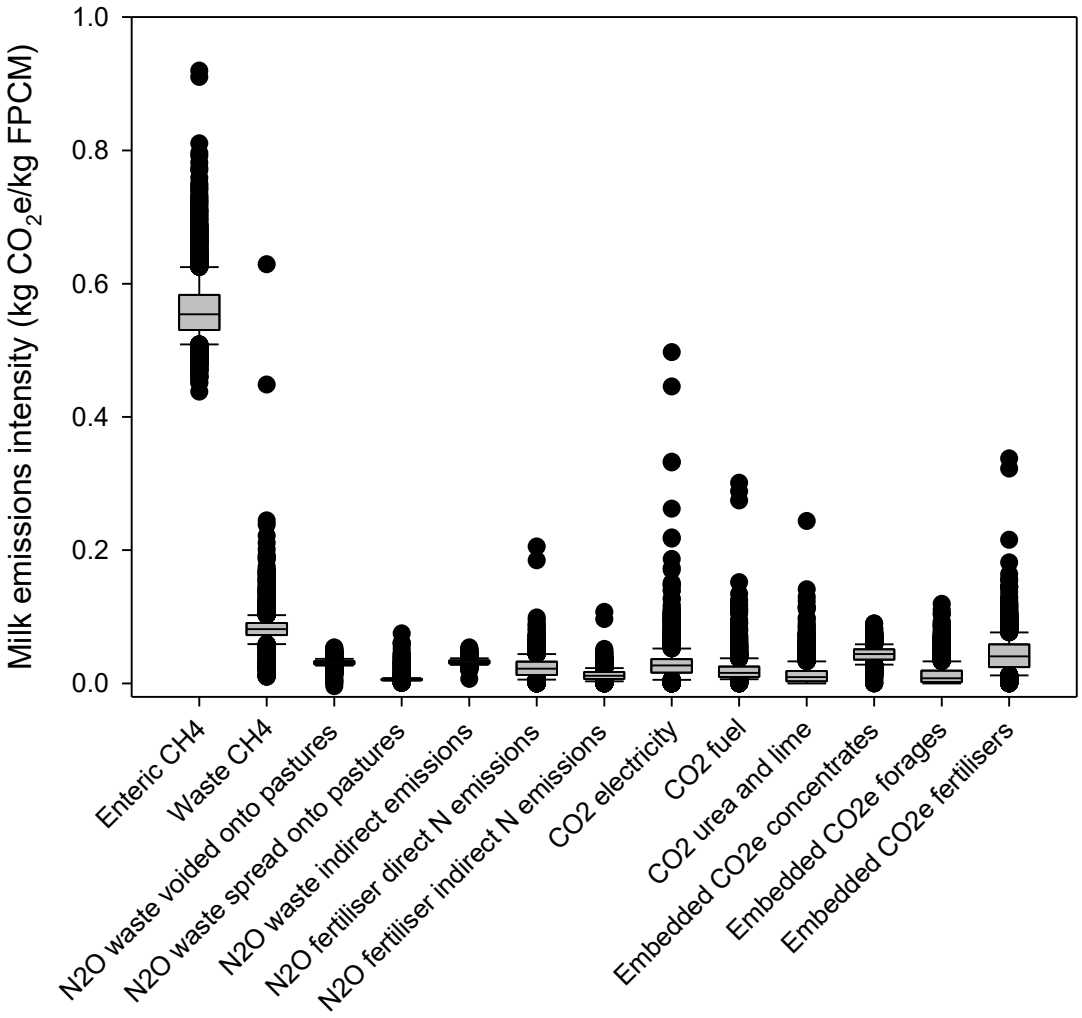


Figure 44. Emissions intensity for each source of on-farm GHG emissions for the 2,141 farm datasets. The boxes represents the 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, dots represent outliers, and solid lines in the boxes represent the medians.

There was 90 datasets indicating tree plantings on farm, and therefore carbon sequestration. However, we must note that estimates of tree carbon sequestration has changed in recent years, and thus we should not be considering the 90 datasets as a percentage of the overall 2,141 completed datasets, rather a smaller denominator should be considered. In addition, some of these 90 datasets are farms repeated every year, thus not individual farms with trees present. Of the farms with tree carbon sequestration, average milk emissions intensity was 0.912 kg CO_2e/kg FPCM prior to considering tree carbon sequestration, reducing to 0.857 kg CO_2e/kg FPCM after including tree carbon sequestration, representing a 6.1% decline in EI. Median EIs were more closely aligned, declining by around 3.4% from 0.908 kg CO_2e/kg FPCM to 0.877 kg CO_2e/kg FPCM. One farm's total farm emission was estimated at 749 t CO_2e/annum. When including tree carbon sequestration, net farm emissions declined to -1,091 t CO_2e/annum, thus the farm could be considered a net sink of GHG emissions assuming accuracy of the tree carbon sequestration. Therefore, while trees on farm reflect a management intervention to reduce on-farm GHG emissions, of the farms with trees already present, the reduction in net farm emissions intensity is minimal.

One issue with presenting averages is they disguise the variation of results between farms. Figure 45 illustrates the range of EIs for farms in Victoria, New South Wales and South Australia that have participated in the last 10 years from 2013/14 to 2022/23, totalling 33 farms. Note 2016/17 had these farms participating in the DFMP. However, with only a few farms with all data present to be classified

sufficient for analysis, the balance were missing critical data (electricity and/or diesel consumption and associated GHG emissions), we excluded all 2016/17 datasets from this graph.

The median (horizontal line in each boxplot) has remained relatively consistent within the 0.89 to 0.93 kg CO_2e/kg FPCM range for all years (Figure 45). While the median milk EI was declining from 2019/20 through to 2021/22, there has been a slight increase in milk EI in the last year of data analysis. The same methodology has been used for all years, yet only did we collect farm-specific data around manure management in the last year, thus most likely the cause of the upward trend in 2022/23. What we may be able to conclude is that the range between the 25th and 75th percentiles (the box) appears to be smaller than the previous three years. One farm in the last year of analysis indicated a major decline in milk EI due to the newly included 40 ha of 15-year old trees on farm, which has never been included previously, yet usable farm area has not increased in the last year to indicate that this farm may have bought another farm which included pre-established trees. Thus, the accuracy of this result, in fact, all results, are dependent on farmer data entry.

There can also be issues with focusing on single dot points within boxplots, in terms of we have no way of gauging if this trend of individual farm EIs potentially declining is a result of climate conditions, milk prices, key farm input prices or farmers actively managing their farming system to reduce GHG emissions.

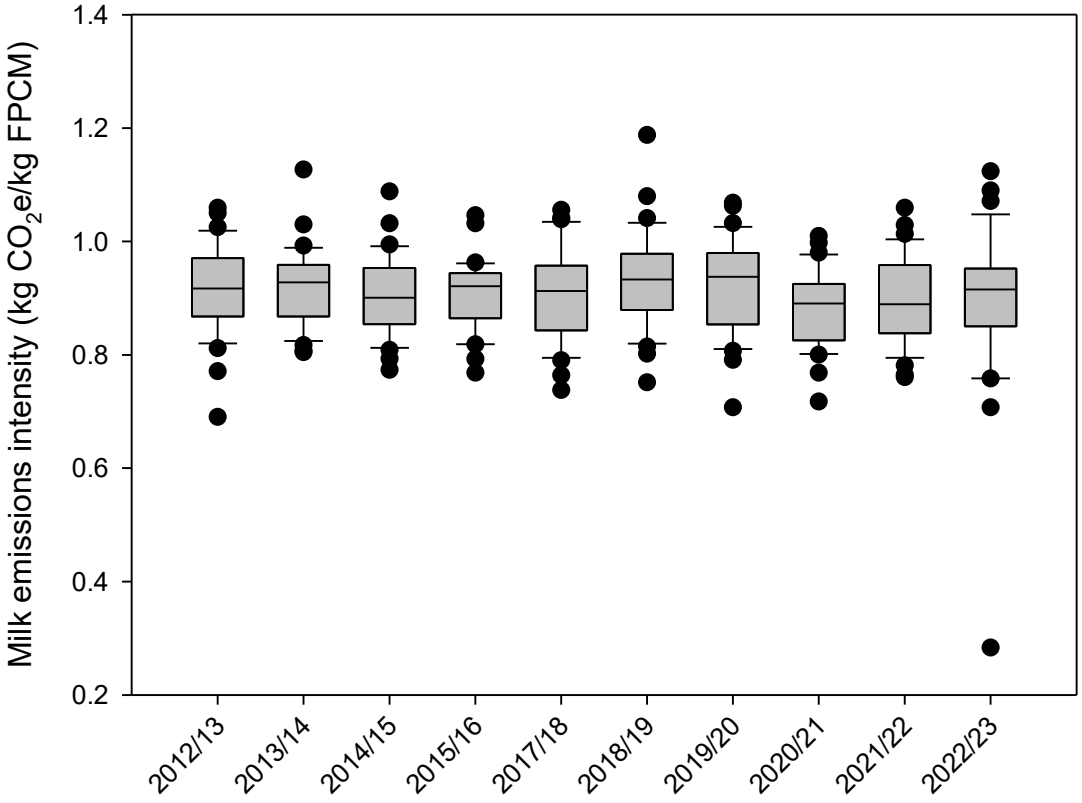


Figure 45. Range of milk emissions intensities, after allocating a proportion of greenhouse gas emissions to meat, across Victorian dairy farms that have participated in 10+ years of the Dairy Farm Monitor Project. The boxplot represents the 25th to 75th percentiles, the whiskers represent the 10th and 90th percentiles, the dots represent the outliers and the horizontal line in the box represents the 50th percentile (median). The numbers above each boxplot represent how many farms attributed to the boxplot results. FY 2007 reflects the 2006-07 financial year.

A review of the relationship between EI and milking herd size found no clear correlation (Figure 46). The red dotted line in Figure 46 represents the average EI across the dataset, at 0.91 kg CO_2e/kg FPCM, noting that this average is simply an average of all datasets, not a milk production-weighted milk EI.

Visually, most farms with EIs above 1.0 kg CO_2/kg FPCM tend to be smaller herds. However, once the milking herd is > 1,000 cows, there appears to be a relatively equal spread of farm with EIs either higher or lower than the overall average. Some small herds (< 500 milkers) have milk EIs below 0.5 kg CO_2e/kg FPCM, indicating they have carbon sequestration in trees to offset some/all of their livestock and farm-derived emissions. Therefore, if herd size increases within the dairy industry, as it has done previously (Dairy Australia, 2022), it is hard to gauge whether this alone will result in either an increase or decrease in the EI of milk production.

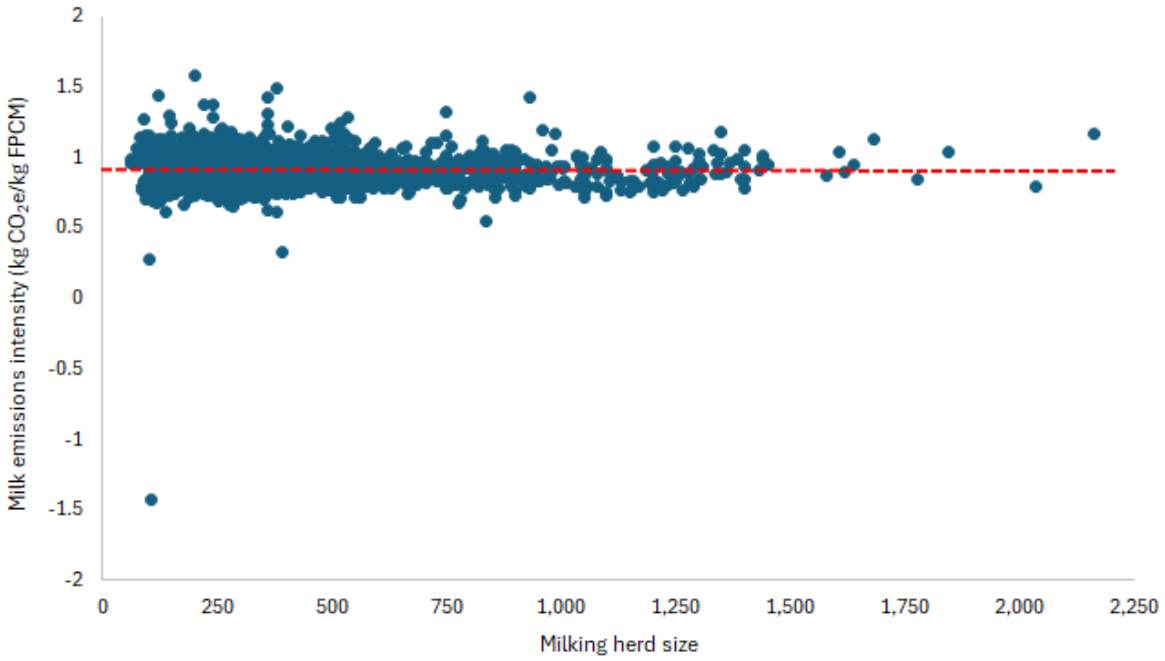


Figure 46. Relationship between milking herd size and emissions intensity. The red dotted line represents the linear regression relationship between herd size and emissions intensity.

There is a trend that increasing milk production per cow dilutes net GHG emissions and thus reduce the EI of milk production (Figure 47). Farms with low milk production per cow (< 4,000 litres per lactation) tended to have higher EIs; there was less milk to dilute net farm GHG emissions. In contrast, a review of those farms where cows were producing > 10,000 litres/lactation found that many of these appear to be total mixed ration farms given some exhibited a very small milking platform (< 10 ha), resulting in a dilution of net farm GHG emissions. It must be noted that many of those farms with very high milk production per cow combined with low milking platform area and low proportion of the overall diet from grazed pastures, indicative of partial or total mixed ration farms, still used the state-based default factors as the changeover to farm-specific manure management data entry only commenced in the last year of assessment. This would underestimate waste CH_4 and N_2O emissions from stored manure, thus net farm emissions and EIs. The only two exceptions are the farm producing ~ 13,000 litres per cow and an EI of 1.31 kg CO_2e/kg FPCM (clearly visible), while the second farm that implemented user-defined manure management indicated that 100% of their milker manure was deposited onto pastures, however other components of data entry suggest they have a feedpad used for 4 hours per day, year round, thus data entry has been compromised here, leading to a low milk EI of 0.89 kg CO_2e/kg FPCM (not visible in Figure 47). The option to use state-based factors or user-defined factors has been available for several years now and thus is an area which needs focusing on, and with greater accuracy of data entry, with DFMP data collection to better reflect on-farm practices and thus net farm GHG emissions and EIs.

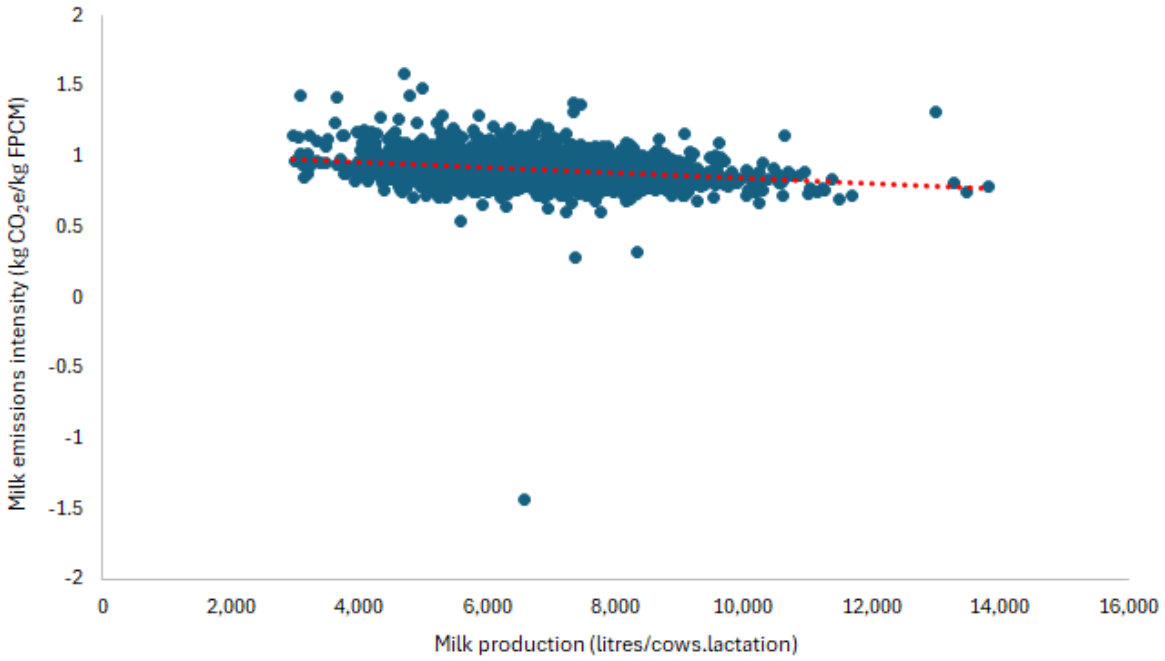


Figure 47. Relationship between milk production per cow and emissions intensity. Red dotted line represents the linear regression relationship between milk production and emissions intensity.

One way to compare your results to other farms is to review your farm's milk efficiency. A common target used in the dairy industry is to produce 1 kg of milksolids per kg of milking cow liveweight. Figure 48 illustrates that there is a trend of reducing EIs as this milk efficiency ratio increases. By targeting > 1 kg milksolids per kg of liveweight, GHG emissions can be diluted by increased milk production. The low R^2 of ~ 0.25, in addition to the many dots sitting some distance from the dotted line, indicates that while there is a trend, milk efficiency is a poor surrogate for estimating EI. In addition, Figure 48 suggests there is a point, at approx. 1.2 kg milksolids/kg liveweight, at which an increase in milk efficiency is unlikely to result in a reduction in EI. We purposely removed the one farm with a negative EI due to this farm altering the scale of the y-axis, thus creating the illusion of a more horizontal polynomial curve.

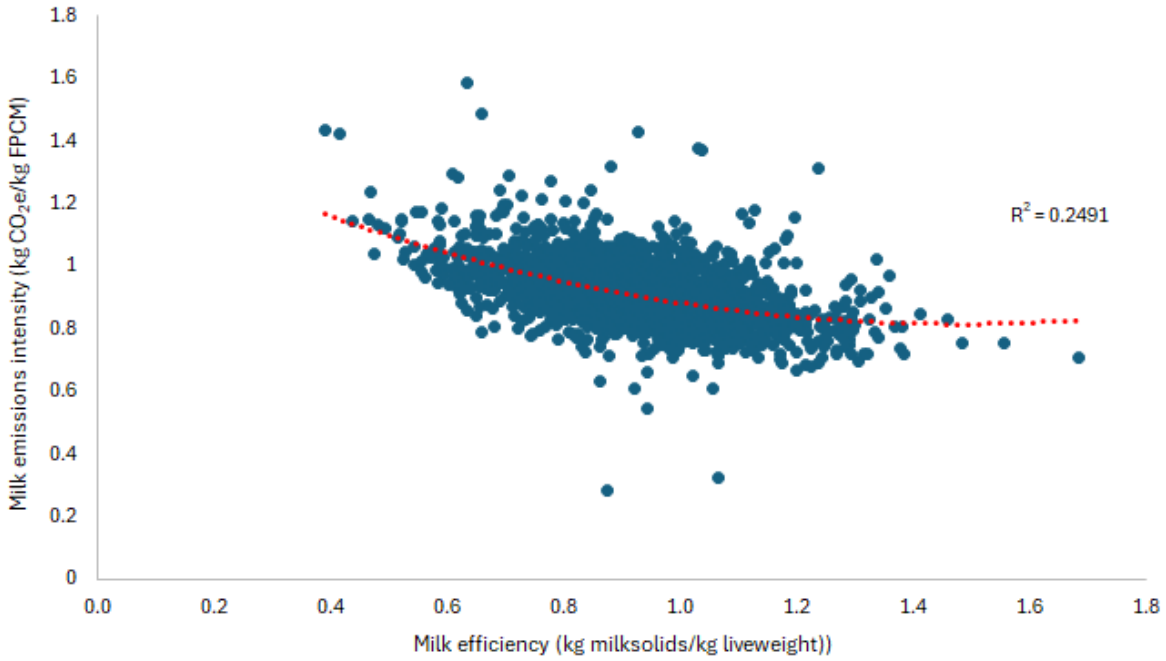


Figure 48. Relationship between milk efficiency (kg milksolids/kg liveweight of the milking cow) and milk emissions intensity (kg CO_2e/kg FPCM).

One way to improve milk production per kg of liveweight is by increasing the energy density of the diet through grain/concentrate feeding. Figure 49 illustrates the relationship between milk efficiency and EI for four grain feeding groups; low (< 1 t DM/cow.annum), medium (1-2 t DM/cow.annum), high (2-3 t DM/cow.annum) and very high (> 3 t DM/cow.annum). It must be noted that when undertaking this assessment, it was assumed that all grain/concentrates were fed to the milking cow. This may not always be the case if young stock is also fed grain (e.g. pre-weaned calves to develop their rumen and farms which raise dairy beef with some grain supplementation). For example, there was 21 farms feeding over 4 t DM/cow.annum which is unlikely to be a feeding rate isolated to just the milking cow. However, the milking herd will still consume the majority of purchased grain/concentrates. The average EI was 0.96 kg CO_2e/kg FPCM for the low grain feeding group, there was only a minor difference between the medium and high grain feeding groups, with a mean EI of 0.91 and 0.90 kg CO_2e/kg FPCM, respectively. The average EI of the very high grain feeding farms was 0.92 kg CO_2e/kg FPCM, further confirming that some of the grain fed in the very high grain feeding group was not necessarily fed to the milking herd cows. In addition, as the rate of grain feeding increased, the variation between the 10th and 90th percentile dataset EI within each grain feeding group declined (data not shown). Thus, it can be concluded that increased grain feeding reduces the variability of EI within each grain feeding group. NOTE: We purposely removed one dataset with a milk EI at ~ -1.5 kg CO_2e/kg FPCM as including this dataset extended the y-axis, thus compressing the other dataset points.

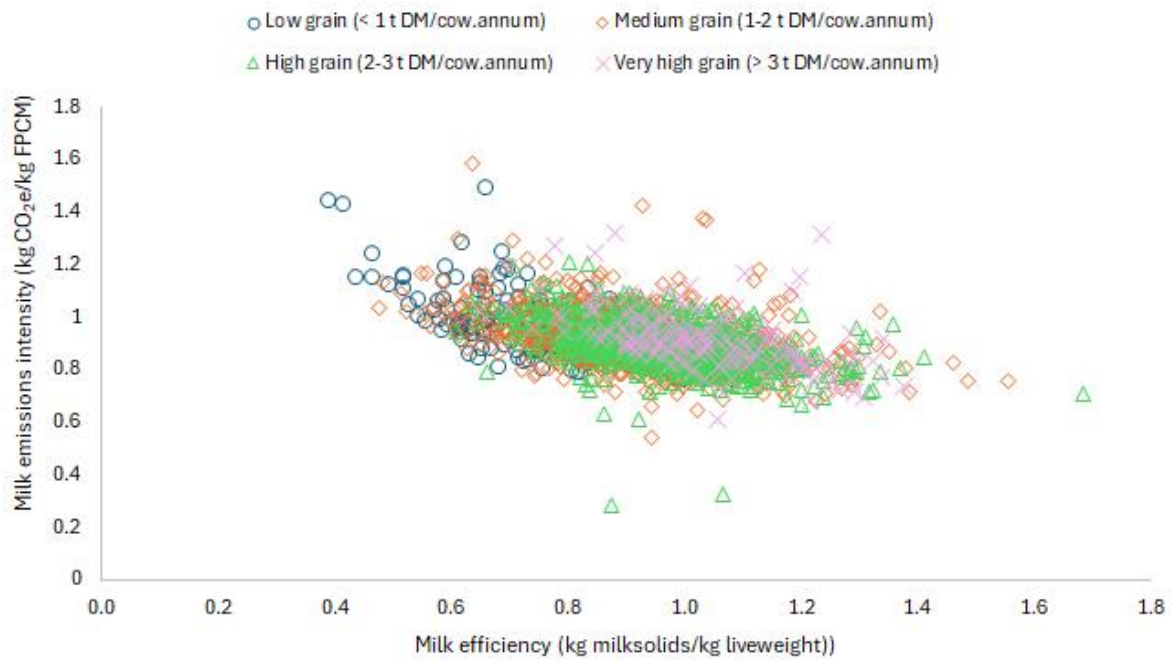


Figure 49. The relationship between milk efficiency (kg milksolids/kg liveweight) and emissions intensity (kg CO_2e/kg FPCM) for low grain feeding (< 1 t DM/cow; blue circles), medium grain feeding (1-2 t DM/cow; orange diamonds), high grain feeding (2-3 t DM/cow; green triangles), and very high grain feeding (> 3 t DM/cow; pick crosses).

Another key input to dairy farms that contributes to net GHG emissions is N fertiliser. Figure 50 illustrates the relationship between N fertiliser inputs (kg N/ usable ha) and EI (kg CO_2e/kg FPCM). Note that usable hectares also include runoff/outblocks, and thus the rate of N applied may be lower than applied to the milking platform. There was a trend towards a slight increase in mean EIs as the rate of N fertiliser/ha increased. The two lowest N fertiliser groups (< 50 kg N/ha (blue circles) and 50-100 kg N/ha (orange triangles) mean EI was 1.01 kg CO_2e/kg FPCM. Mean EI increased to 1.03 kg CO_2e/kg FPCM for the 100-175 kg N/ha fertiliser group (green triangle), while Ei increased further to 1.07 kg CO_2e/kg FPCM for the highest N fertiliser group (> 175 kg N/usable ha; pick crosses in Figure 50). The 50 to 100 kg N/usable hectares illustrated the smallest range in EI, while the very high N fertiliser rate farms had quite a spread of EIs. Thus fertiliser alone is not a key determinant of milk EI. Any farm, irrespective of their level of N fertiliser, if they are excellent at converting N fertiliser into high-quality forage, which is efficiently grazed/conserved, and then converted into milk production, this will assist to dilute the GHG emissions associated with N fertiliser inputs. NOTE: we purposely removed one dataset that indicated a fertiliser rate > 1,000 kg N/usable hectares as well as the one dataset with a milk EI at ~ -1.5 kg CO_2e/kg FPCM as including this dataset extended the y-axis, thus compressing the other dataset points.

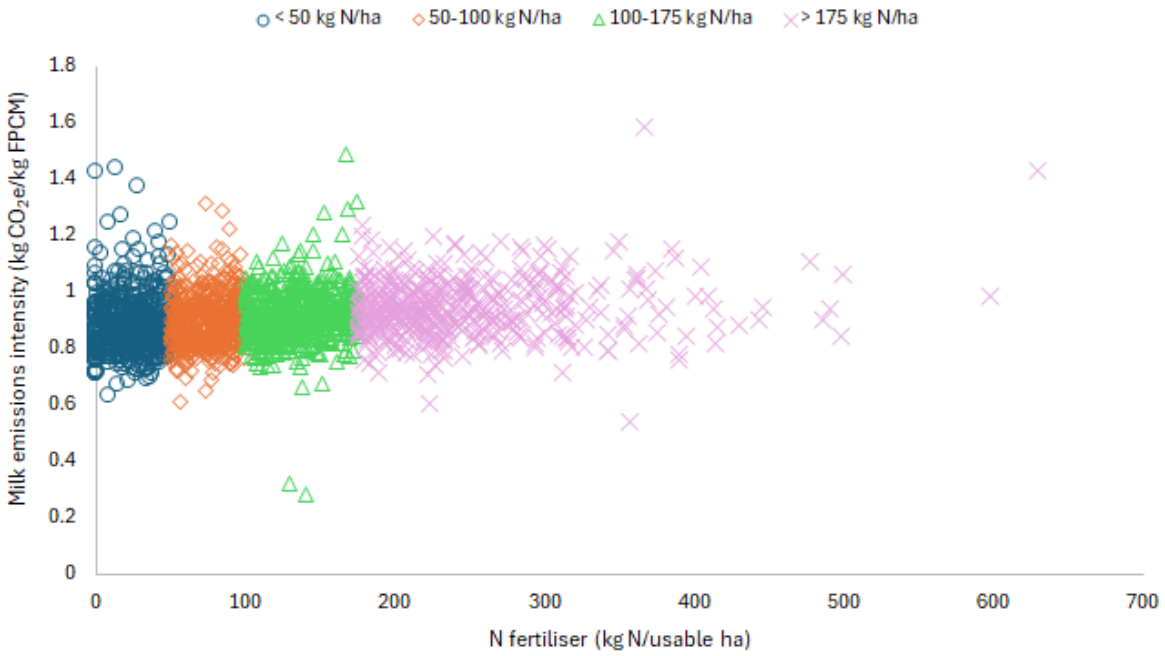


Figure 50. The relationship between N fertiliser inputs (kg N/usable hectare) and emissions intensity (kg CO_2e/kg FPCM) for four N fertiliser ranges. Low (< 100 kg N/ha; blue circles), medium (100-199 kg N/ha; orange diamonds), high (200-299 kg N/ha; green crosses), and very high (> 300 kg N/ha; purple triangles).

7. Profitable Emissions Action Plan

A new introduction to ADCC, implemented with version 6.1, is a Profitable Emissions Action Plan (PEAP) located within the 'Action Plan' and 'Action Plan Report' tabs). Comparing your farm data against a regional or system benchmark can be useful in identifying inefficiencies and potential areas of improvement (Figure 51). Users can save and then share or print this graph by going to the 'Action Plan Report' tab and clicking on the PDF button on the top right corner of the sheet under the TIA logo. However, before taking steps to identifying and implementing emissions reduction activities, it's important to first reflect on the data that you have used to generate your estimate. By answering questions several questions, you will gather an understanding of your confidence in your data and if you are able to start investigating emissions reduction activities for your farm. If this is your first time completing a footprint, you may wish to focus on simply improving your records management as your first priority. If this is the case, you can still print a summary report for your records (or a third party) on the 'Data Summary' tab.

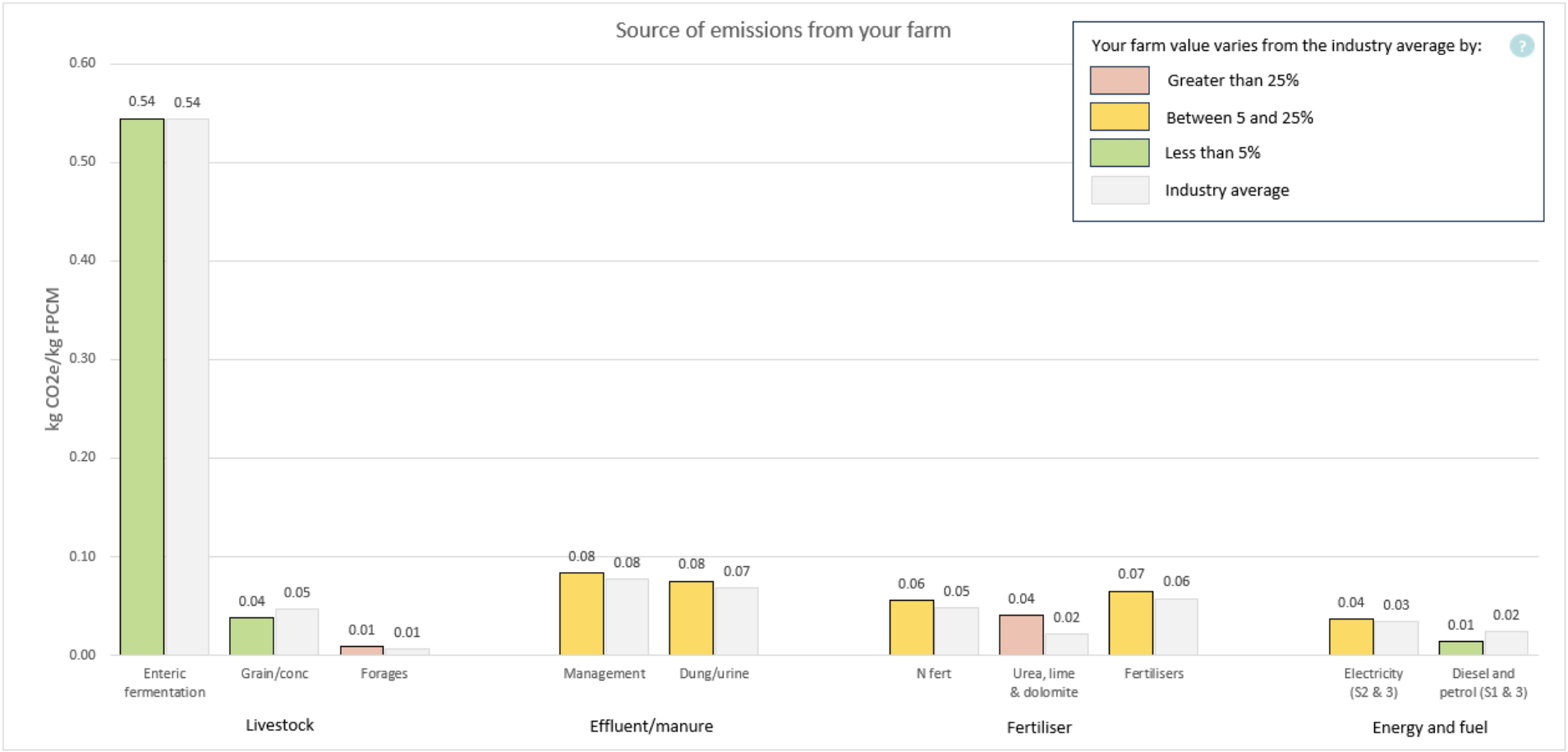


Figure 51. Comparison of Your Farm emissions to that of South-West Victoria based on the farm system explored in the manual.

The first question asks users to reflect on how confident they are in terms of the accuracy of data entry in reflecting farm activities? From here, users can then select one or more areas which they have low confidence in and comment on ways to improve this (Figure 52).

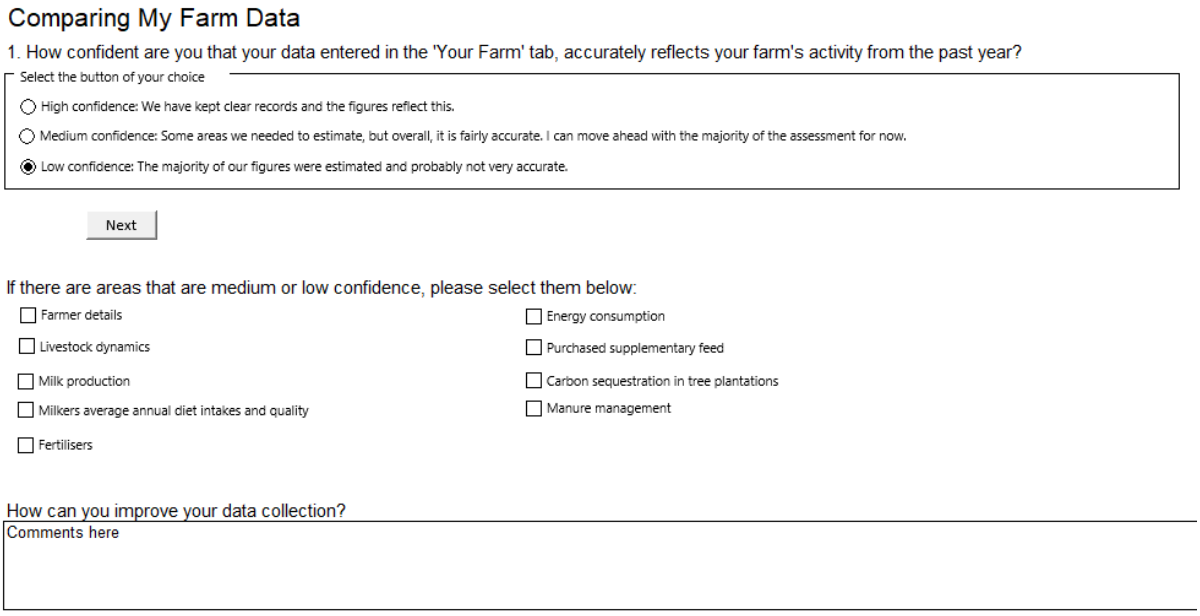


Figure 52. Screenshot of the Action Plan asking users their confidence in data entry and giving them space to make comments as to ways they might improve data collection.

The next two sections self-populates by indicating which parts of the emissions profile are lower or higher than the industry average, asking users to reflect on which factors could have influenced these results? For example, Figure 53 shows that several sources of emissions were higher than the industry average, e.g. enteric methane, N fertiliser, manure management, and electricity. Note that the ticks do not necessarily mean substantial variation to the regional average. This is better illustrated with the graph where differences to the regional average are highlighted via a traffic light system with < 5% difference shown as green columns, 5-25% difference shown as orange columns, and > 25% difference shown as red columns. For the farm explored throughout this manual (Example farm system), CO_2e emissions from urea and lime/dolomite, and Forages to a lesser extent, were the only sources with greater than 25% difference to the regional average (Figure 51).

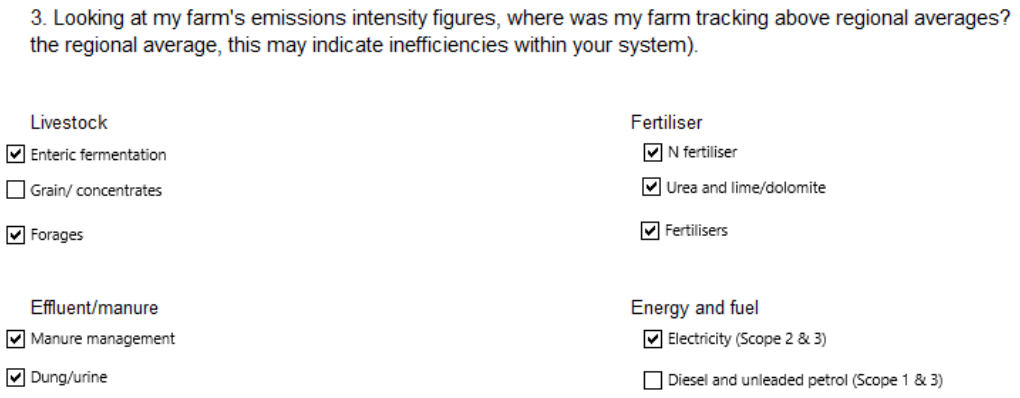


Figure 53. ADCC has self-populated the Action Plan to show that the farm has higher emissions intensity than the industry average in all four key areas.

Users are then asked, ‘Am I in a position to make changes in my farm management?’ (Figure 54). If the answer is yes, users can then click on one or more areas they wish to explore in terms of options to reduce their GHG emissions.

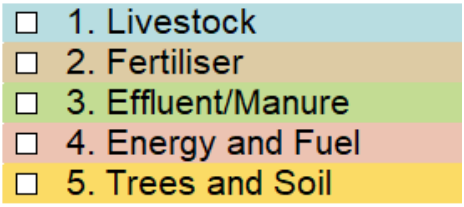


Figure 54. Currently we have five key areas of farm management to explore in terms of options to reduce GHG emissions.

By clicking in the box for an area to explore, a range of options become visible, with a range of resources and information becoming visible. There are five broad areas to explore – Livestock, Fertiliser, Effluent/Manure, Energy and Fuel, and Trees and Soil. In Figure 55 below, we can see a series of steps from 1. Livestock to 1.1. Feedbase and Diet and further down to 1.1.1. Intervention: Balancing protein to energy ratio. Users may decide to explore an option within the COST section of ADCC (see section 8), or click on links to resources etc. Importantly, at the bottom of each subsection, there is a ‘My Action’ section to document the action(s) you plan to take (Figure 56).

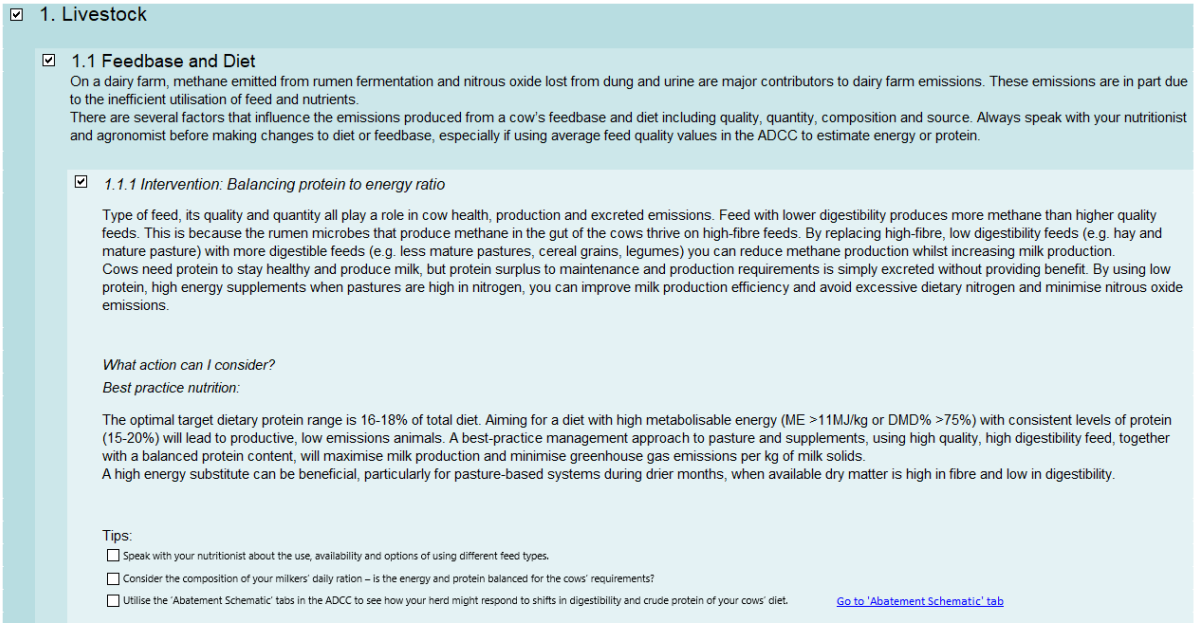


Figure 55. Expansion of the option ‘Balancing the protein to energy ratio’ within the Feedbase and Diet subsection of the Livestock section within PEAP.

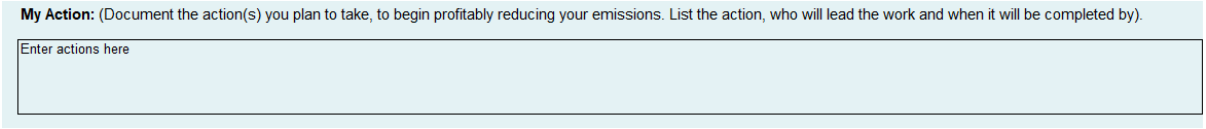


Figure 56. Users are encouraged to identify action(s) planned to being profitably reducing farm GHG emissions.

8. Abatement options (Carbon Offset Scenario Tool)

There have been many scientific reviews of abatement options over the years for ruminant livestock, with a few more specific to Australian conditions. Examples have been included in the Resources section later in the manual, although access to the general public may be limited, especially reviews in journal papers.

Within ADCC, we have built the Carbon Offset Scenario Tool, simplified to COST, to explore a range of potential abatement options to reduce GHG emissions. Users can either access the Abatement Schematic worksheet (Figure 57) or scroll through all the sheets to locate the tab you wish to use. These strategies are broadly grouped into four categories:

1. Herd and breeding management options to reduce enteric CH_4 and/or N_2O emissions,
2. Diet manipulation to reduce enteric CH_4 and/or N_2O emissions,
3. Feedbase management to reduce N_2O emissions, and
4. Whole farm abatement to reduce CO_2, CH_4 and/or N_2O emissions.

Within ADCC, each green box is hyperlinked to the appropriate abatement option. For example, clicking on the Extended lactation box takes the user to the Extended lactation abatement option. Alternatively, you may wish to explore multiple aspects of the farm system, or an abatement option that is not listed. To do this, click on the brown Whole farm abatement strategy circle. This will progress you to the pre-populated 'Strategy Farm' tab. This new tab contains the 'Your Farm' data, which can now be altered.

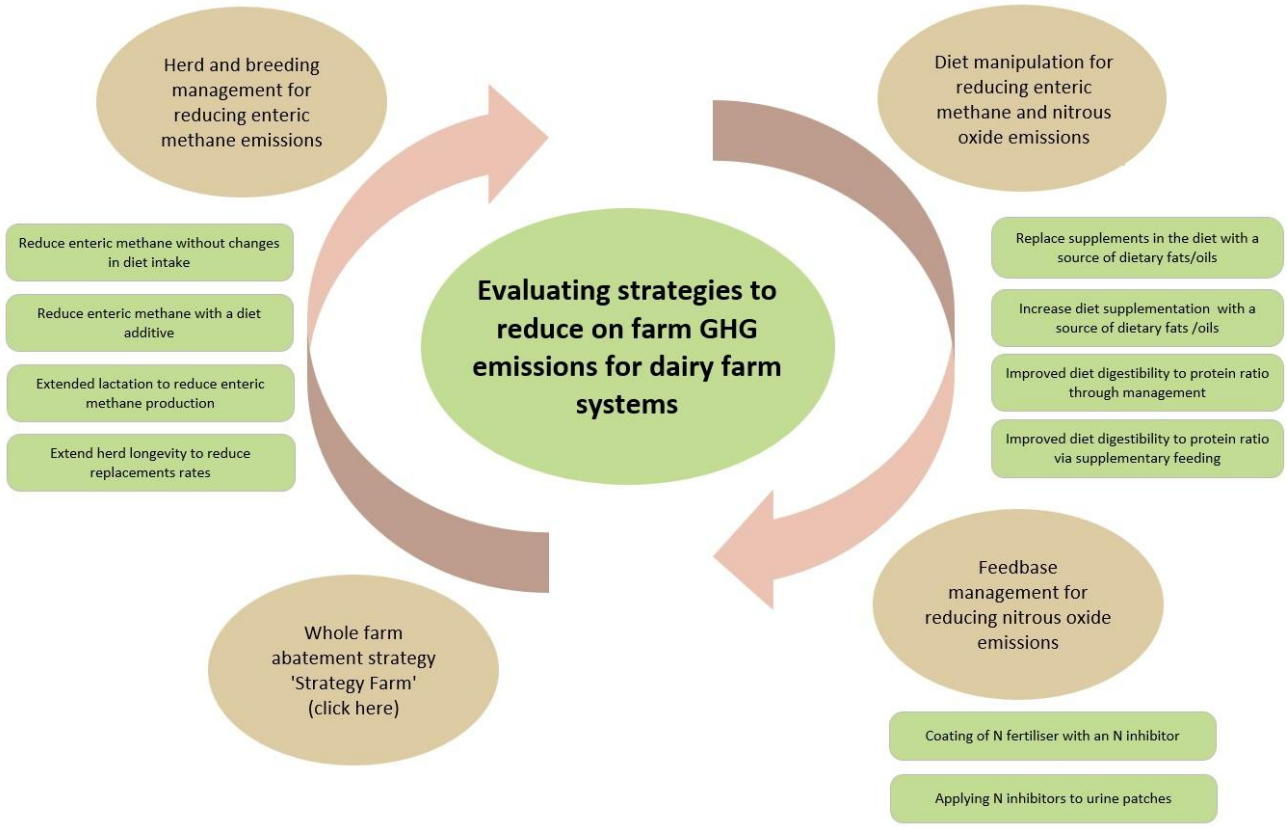


Figure 57. Schematic illustrating the various abatement options that can be explored in the ADCC.

Note: The examples explored in this manual are only a guide to give users an indication of how to select the key variables for each strategy. Users need to determine these key variables for their specific circumstances. Results for your farm will vary from the results below due to a range of factors, such as herd size and structure, milk production, overall diet DMD, CP, and fat quality, the use of N fertilisers, milk price, and carbon credit prices.

All abatement options have a section across the top of their corresponding tab explaining what the abatement is designed to explore (Figure 58). For example, *Reducing Enteric Methane and/or Improved Milk Production Without Changes to Intakes* ('Reduce CH_4 and or Increase milk' tab) explores options that will focus on reducing enteric CH_4 emissions through management or breeding with or without an improvement in milk production. Examples include management options such as high sugar ryegrass pastures that supply more energy per kg of dry matter. Breeding options include retaining cows that produce more milk per kg dry matter intake or selecting semen from bulls with proven reduced CH_4 emissions.

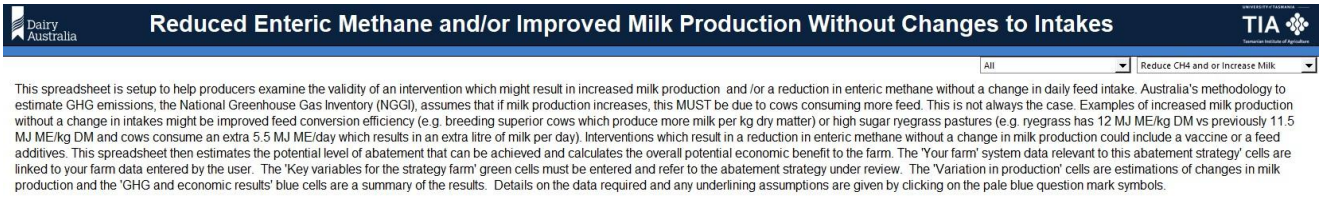


Figure 58. Screenshot of the top banner explaining the abatement intervention for the *Reducing Enteric Methane and/or Improved Milk Production Without Changes to Intakes* intervention (tab listed as Reduce CH_4 and or Increase milk).

Following this descriptor section, down the left-hand side of the tab, the first box is titled **Your farm system data relevant to this abatement strategy** (Figure 59. This data is self-populated when entering your 'Your Farm' data, with the one exception. The Extended lactation adaptation option tab asks for additional information which cannot be gathered when entering the 'Your Farm' data (see section 8.3 for more information specific to Extended lactations).

Your farm system data relevant to this abatement strategy	
Your farm number of milkers	450
Average liveweight of milking cow (kg)	500
Average annual milk production (litres/cow.day)	22.2
Average lactation length (days)	300
Average annual diet dry matter digestibility (%)	75.7
Average annual diet crude protein (%)	18.6

Figure 59. Screenshot of the first section illustrating some key 'Your Farm' data related to the 'Increase diet supplementation with a source of dietary fats/oils' abatement option.

The next section is titled **Key variables for the strategy farm** (Figure 60). These are a series of questions specific to the abatement strategy being explored. The cells needing data are all coloured green and contain up/down arrows to select the most relevant answer to the question asked. For example, in Figure 60, the first question requires the user to estimate the percentage reduction in enteric CH_4 due to changes in management or breeding using the up/down arrows so that the number in the green cell best matches the required number. Here we have determined that enteric CH_4 is reduced by 30% combined with an increase in milk production of 0.8 litres/cow per day from a diet that remains the same as the baseline 'Your farm' diet. The green cells are protected, so the user can only alter the values by using the up/down arrows; you can't type in the new value in the green cell.

Sometimes when clicking on the up arrow, values will decrease, and likewise clicking on the down arrow, values will increase. This is because the box containing the arrows is rather small and you mouse, while it looks to be in the right place, the box doesn't quite align. If this occurs, increase your screen size by zooming in. If you are using a mouse, the easiest way is to click on Ctrl on your keyboard and at the same time, roll the scroll button up on your mouse. This should make everything larger on your screen so that you mouse can then correctly click on either the up or down button and values alter accordingly.

In some instances we separate data entry into increments of 0.1 (e.g. DMD% and CP%), or 0.25 (e.g. on-farm price received for a tonne of CO_2e) to reduce the amount of scrolling required. Select the closest number to match your required data entry. For example, if the price received on-farm for carbon was $17.15, select $17.25 as this is closer than $17.00. Help messages throughout the sheets, highlighted by the red triangle in the top-right corner of the question cells, explain what information is required for each data entry green cell.

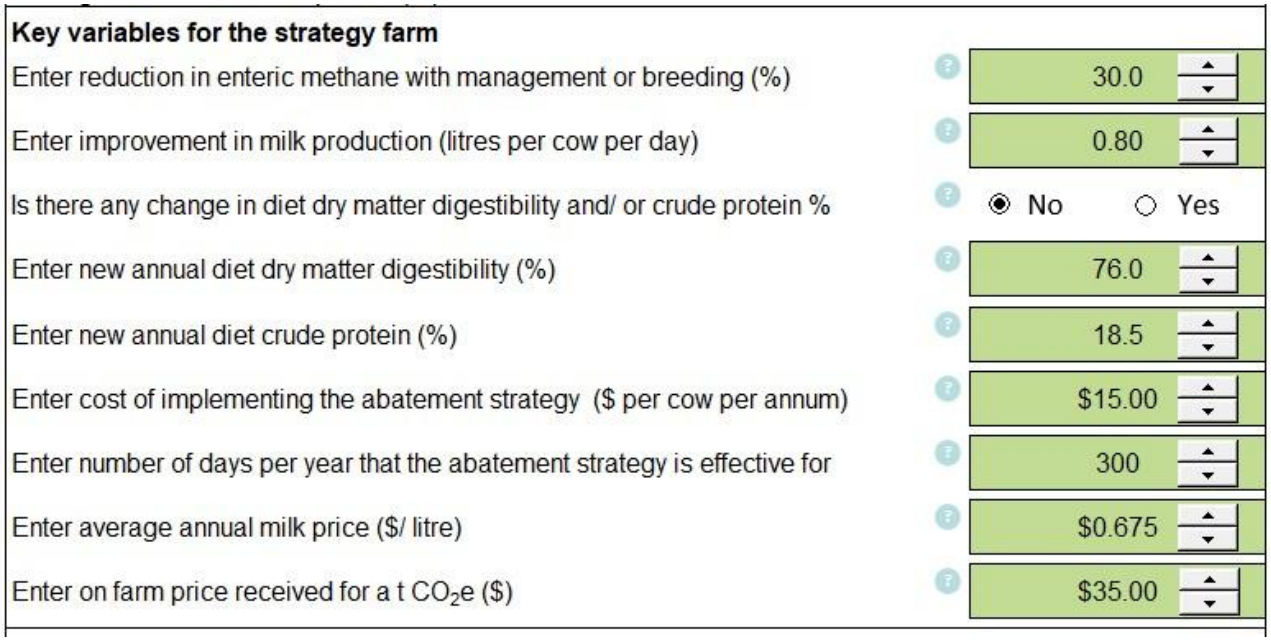


Figure 60. Screenshot of the Key variables section illustrating all the questions relevant to the 'Increase diet supplementation with a source of dietary fats/oils' abatement option. Using the up/down arrows will progress the number in the corresponding green cell.

The third section is titled **Variation in production** (Figure 61). This section varies between abatement strategies explored. Where the strategy implemented results in an aspect relevant to milk production, this is reported in this section. For example, in Figure 61, the abatement strategy resulted in an estimated extra 108,000 litres of milk produced, relative to the 'Your Farm' system.

While not relevant for this specific strategy, but others, we have set some limits on how much the data entry can alter. For example, where the strategy implemented results in an increase in the dietary fat content of the diet, we have set an upper limit of 7%. Diets with fat contents above 7% will result in a depression in milk production and other potential animal health implications. If you enter a supplement that lifts the overall diet fat content above this trigger point, text will appear stating TOO HIGH, milk production will become 0, and the graph will become blank. If this occurs, you need to either reduce the amount of high-fat supplement fed, the fat% of the supplement or a combination of both, so that the overall diet fat content decreases below 7%.

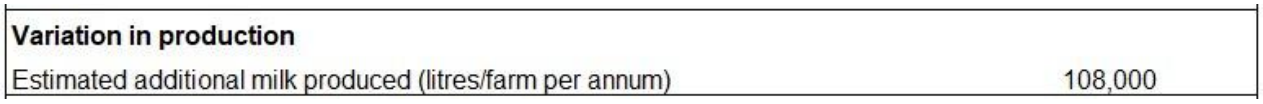


Figure 61. Screenshot of the third section illustrating the fat content and change in milk production with the 'Increase diet supplementation with a source of dietary fats/oils' abatement option.

The last section is titled **GHG and economic results** (Figure 62). These results are consistent for all abatement strategies, indicating:

- reduction in emissions,
- percentage reduction in emissions, relative to the 'Your farm' system,
- potential carbon credit income achieved with the reduction in GHG emissions,
- estimated expenses associated with implementing the strategy,
- the net profit as a stand-alone abatement (i.e. income minus profit prior to any income derived from altered milk production),
- additional milk income,
- estimated total farm benefit considering changes in milk income, and
- carbon credit income, as a percentage of your farm milk income.

Each result has a note with information related to the result, as indicated by the question mark of each result description. A negative reduction in GHG emissions reflects an increase in GHG emissions.

GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	406.5
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	0.0
Reduction in animal waste N_2O emissions (t CO_2e/annum)	1.8
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	408.4
Reduction in net emissions, relative to the 'Your farm' system (%)	11.7
Reduction in CH_4 emissions, relative to the 'Your farm' system (%)	21.0
Reduction in N_2O emissions, relative to the 'Your farm' system (%)	0.8
Calculated potential carbon credit ($ per farm)	$14,292
Calculated expense to implement the strategy ($ per farm)	$6,750
Benefit as stand alone abatement ($ per farm)	$7,542
Estimated additional milk income ($ per farm)	$72,900
Estimated total farm benefit from strategy ($ per farm)	$80,442
Carbon credit total farm benefit income as % of your farm milk income	3.97%

Figure 62. Screenshot of the results section illustrating the change in GHG emissions, costs of implementation, change in income from milk production, and the estimated total farm benefit of implementing the 'Reduced enteric methane and/or improved milk production without changes to intake' abatement option.

Results are also presented graphically (Figure 63), showing the potential carbon credit, implementation cost, additional milk income, and total farm benefit (i.e. carbon credit + milk income – implementation cost). Note that the economics undertaken here in COST are relatively simple. For example, a scenario that results in increased milk production would most likely require additional electricity to harvest this additional milk. These additional electricity costs are not included in the total farm benefit; this result is simply carbon credit + milk income – implementation cost as defined by the user's inputs and COST estimations.

By using the up/down arrows, users can realise the sensitivity of data entry on overall profit. If the cost to implement plus a change in milk income (which can become negative if milk production declines) is more than the income from carbon credits, then total farm economic benefit can become negative. Section 8.8 is an excellent example of this. Based on the changes implemented with that scenario, net GHG emissions declined, and milk production was predicted to increase. However, the cost of implementation was greater than the sum of additional income from milk production and carbon credits, resulting in a negative total farm benefit.

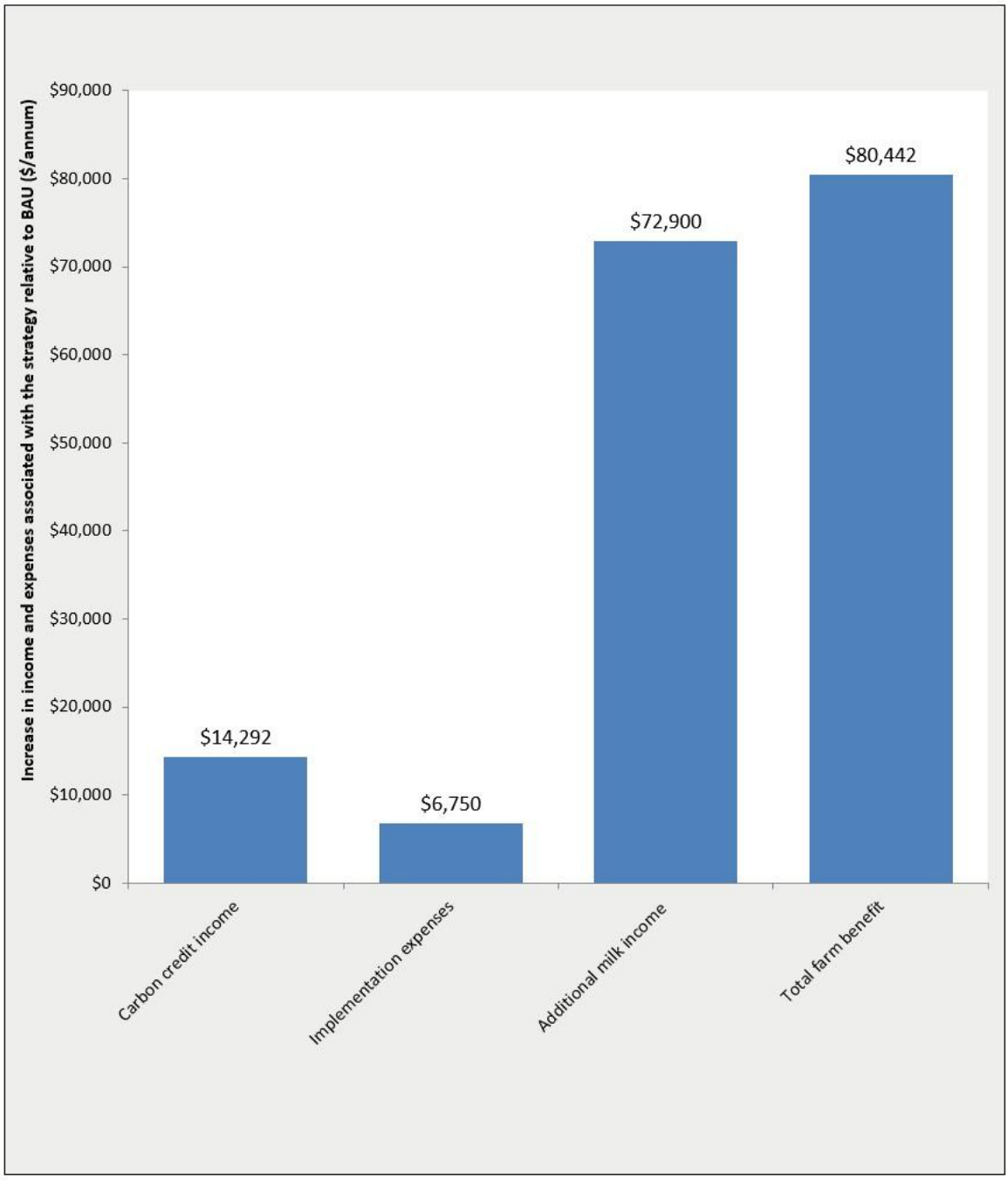


Figure 63. Screenshot of the results of an abatement strategy to reduce enteric methane production through the feeding of dietary fats & oils. The strategy generated $489 in carbon credits, cost $40,500/annum to implement, and increased income from milk production by $60,394/annum, thus total farm benefit was $20,383/annum. Users can quickly ascertain the effect of altering one or more of the key input numbers, such as fat content of the new supplement or substitution rate of the dietary fat, on overall farm GHG emissions and profit.

8.1. Reduced enteric methane and/or improved milk production without changes to intakes

When first building COST within ADCC, we had a strategy that explored options to reduce enteric CH_4 emissions through herd management. Over time, we have not been happy with the estimates within this strategy as the NGGI methodology assumes that if milk production increases, this **must** be due to an increase in intake and thus enteric CH_4 production. We also did not have a strategy that could explore feeding a diet with increased DMD/ metabolisable energy that would supply additional energy for milk production but not alter intakes. We have re-organised the previously named *Reduce enteric CH_4 through breeding or management* to now allow a combination of options to be explored.

a) Management option where animal produce lower CH_4 emissions per unit of feed intake, through a vaccine or feeding small amounts of additives which reduces enteric CH_4 emissions (e.g. *Asparagopsis taxiformis*, 3-NOP trading as *Bovaer*® or Agrolin®). This option may or may not result in any improvement in milk production, relative to the 'Your Farm' system,
b) Breeding option where animals are genetically superior, thus either producing less CH_4 emissions per unit of feed intake, produce more milk per unit of feed intake, or a combination of both,
c) Management option of including high-sugar ryegrass pastures into the sward (e.g. 12 MJ ME/kg DM vs 11.5 MJ ME/kg DM with standard ryegrass cultivars) to increase milk production which should increase milk production without any change in enteric CH_4 production.

For all options, we allow for a change in diet DMD% and/or CP%. If the diet's DMD% changes, while this will not impact enteric CH_4 emissions, it will affect waste CH_4 emissions. For example, an increase in DMD% results in a more digestible diet, thus lowering volatile solids production (manure) which will in turn will reduce waste CH_4 emissions. Another example is that if the diet's CP% increases, relative to the baseline 'Your farm' system, the amount of N excreted in urine will also increase, resulting in an increase in waste N_2O emissions.

Note that if you want to explore feeding a supplementary feed high in dietary fat (e.g. brewer's grain or whole cottonseed) to reduce enteric CH_4 emissions, you need to progress to either section 8.5 or 8.6 where overall diet quality may alter.

We have not incorporated a reduction in enteric CH_4 emissions for all other stock classes, only the milking herd as some strategies, such as a feed additive delivered through the dairy shed may not be available for other stock, like heifers.

Key variables for the strategy farm

There are several questions in the key variables section to determine the percentage reduction in enteric CH_4 with implementation, the cost of implementation, any potential increase in milk production, the duration the intervention is effective, the average annual milk price, and on-farm price received for a tonne of CO_2e (Figure 64).

How are the results of the strategy calculated?

Within the spreadsheet, the enteric CH_4 emission per kg of DMI is reduced proportionally, based on the percentage reduction, and the proportion of the year the strategy is effective. For example, a 30% reduction for 365 days would reduce CH_4 emissions from 20.7 g CH_4/kg DMI to 14.5 g CH_4/kg DMI (i.e. 20.7 x (1-30% reduction potential) x (365 days effective/ 365 days of the year)). If diet DMD% changes, this will not alter diet intakes and subsequently enteric CH_4 emissions. However, it will alter waste CH_4 emissions as per the inventory, as will any changes in diet CP%. Increases in milk production will alter waste N_2O emissions as additional milk means more nitrogen is being exported out of the farm.

Much of the numbers/changes with this intervention will need to be based on scientific literature, advice from the supplier of the additive or vaccine, from your semen supplier if related to genetically superior animals or your agronomist if the intervention explored was reviewing changes in the pasture sward.

Example of results

a) Management option to reduce CH_4 and improve milk production without a change in diet quality

In the example below (Figure 64), a vaccine reduced CH_4 emissions by 30%, is administered to each milking cow once a year, and remains effective for the full 12 months. The vaccine costs $15/milker (price is unknown at the time of publishing this manual so an indicative price is included here), resulting in producing an extra 240 litres/lactation, equivalent to an extra 0.8 litres per day over the lactation length of 300 days. However, there was no change to diet quality with this scenario. The milk price was set at $0.675/litre, while the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was $35/t CO_2e. The strategy resulted in an additional 108,000 litres of milk per annum. Implementation of the strategy reduced total farm GHG emissions by 408.6 t CO_2e/annum, mainly enteric CH_4 emissions. The annum total farm benefit was $80,441, based on a carbon credit of $14,291, an additional milk income of $72,900 and an implementation cost of $6,750 (Figure 64). The net change in farm income, relative to the 'Your farm' milk income, was estimated at 3.97% (Figure 64). In addition, the extra milk might require more electricity for milking and cooling, further reducing net profits as well as GHG emissions from electricity usage.

Key variables for the strategy farm	
Enter reduction in enteric methane with management or breeding (%)	30.0
Enter improvement in milk production (litres per cow per day)	0.80
Is there any change in diet dry matter digestibility and/ or crude protein %	◉ No ○ Yes
Enter new annual diet dry matter digestibility (%)	75.7
Enter new annual diet crude protein (%)	18.6
Enter cost of implementing the abatement strategy ($ per cow per annum)	$15.00
Enter number of days per year that the abatement strategy is effective for	300
Enter average annual milk price ($/ litre)	$0.675
Enter on farm price received for a t CO_2e ($)	$35.00
Variation in production	
Estimated additional milk produced (litres/farm per annum)	108,000
GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	406.5
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	0.0
Reduction in animal waste N_2O emissions (t CO_2e/annum)	1.8
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	408.3
Reduction in net emissions, relative to your farm system (%)	11.5
Reduction in CH_4 emissions, relative to your farm system (%)	20.9
Reduction in N_2O emissions, relative to your farm system (%)	0.8
Calculated potential carbon credit ($ per farm)	$14,291
Calculated expense to implement the strategy ($ per farm)	$6,750
Benefit as stand alone abatement ($ per farm)	$7,541
Estimated additional milk income ($ per farm)	$72,900
Estimated total farm benefit from strategy ($ per farm)	$80,441
Carbon credit total farm benefit income as % of your farm milk income	3.97%

Figure 64. Screenshot of the key variables, variation in production (milk production in this instance), and GHG and economic results of implementing a strategy to reduce enteric CH_4 emissions through management, a vaccine in this instance but could be any intervention that reduced enteric CH_4.

b) Breeding option to increase milk production with no change in enteric CH_4 or diet quality

In Figure 65, we modelled an intervention that increased milk production by 0.8 litre/cow.day for the 300-day lactation. However, there was no change in enteric CH_4 emissions or diet quality. Therefore, unlike most other interventions, this example does not really result in a noticeable reduction in GHG emissions. Like above, we assumed the intervention cost an additional $15/cow.annum (e.g. cost of greater improvement in genetics (semen selection) above that of the 'Your Farm' system). This allows a direct comparison to Figure 64 above where enteric CH_4 emissions were reduced. The milk price was set at $0.675/litre, while the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was $35/t CO_2e. Like that explored in Figure 64, the strategy resulted in an additional 108,000 litres of milk per annum. However, there was now only the small reduction in waste N_2O emissions, due to more nitrogen being exported off farm in milk. The annum total farm benefit was $66,213 based on a carbon credit of $63, an additional milk income of $72,900 and an implementation cost of $6,750 (Figure 65). In this example, the cost of implementation was greater than any income derived by reducing GHG emissions. The net change in farm income, relative to the 'Your farm' milk income, was estimated at 3.27% (Figure 65), as there was little change in GHG emissions, so a lower net profit. In addition, the extra milk might require more electricity for milking and cooling, further reducing net profits as well as GHG emissions from electricity usage.

Key variables for the strategy farm	
Enter reduction in enteric methane with management or breeding (%)	0.0
Enter improvement in milk production (litres per cow per day)	0.80
Is there any change in diet dry matter digestibility and/ or crude protein %	(●) No ( ) Yes
Enter new annual diet dry matter digestibility (%)	75.7
Enter new annual diet crude protein (%)	18.6
Enter cost of implementing the abatement strategy ($ per cow per annum)	$15.00
Enter number of days per year that the abatement strategy is effective for	300
Enter average annual milk price ($/ litre)	$0.675
Enter on farm price received for a t CO_2e ($)	$35.00
Variation in production	
Estimated additional milk produced (litres/farm per annum)	108,000
GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	0.0
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	0.0
Reduction in animal waste N_2O emissions (t CO_2e/annum)	1.8
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	1.8
Reduction in net emissions, relative to your farm system (%)	0.1
Reduction in CH_4 emissions, relative to your farm system (%)	0.0
Reduction in N_2O emissions, relative to your farm system (%)	0.8
Calculated potential carbon credit ($ per farm)	$63
Calculated expense to implement the strategy ($ per farm)	$6,750
Benefit as stand alone abatement ($ per farm)	-$6,687
Estimated additional milk income ($ per farm)	$72,900
Estimated total farm benefit from strategy ($ per farm)	$66,213
Carbon credit total farm benefit income as % of your farm milk income	3.27%

Figure 65. Screenshot of the key variables, variation in production (milk production in this instance), and GHG and economic results of implementing a strategy to improve milk production through a breeding option.

c) Management option to include high-sugar ryegrass pasture in the sward to increase milk production and incorporating a change in diet quality

In Figure 66, we modelled an intervention of including high-sugar ryegrass in the pasture sward. The new ryegrass has 12 MJ ME/kg DM, compared to the 'Your Farm' system standard ryegrass which has 11.5 MJ ME/kg DM. This additional 0.5 MJ ME/kg DM could be equivalent to an approx. 3% improvement in DMD%.

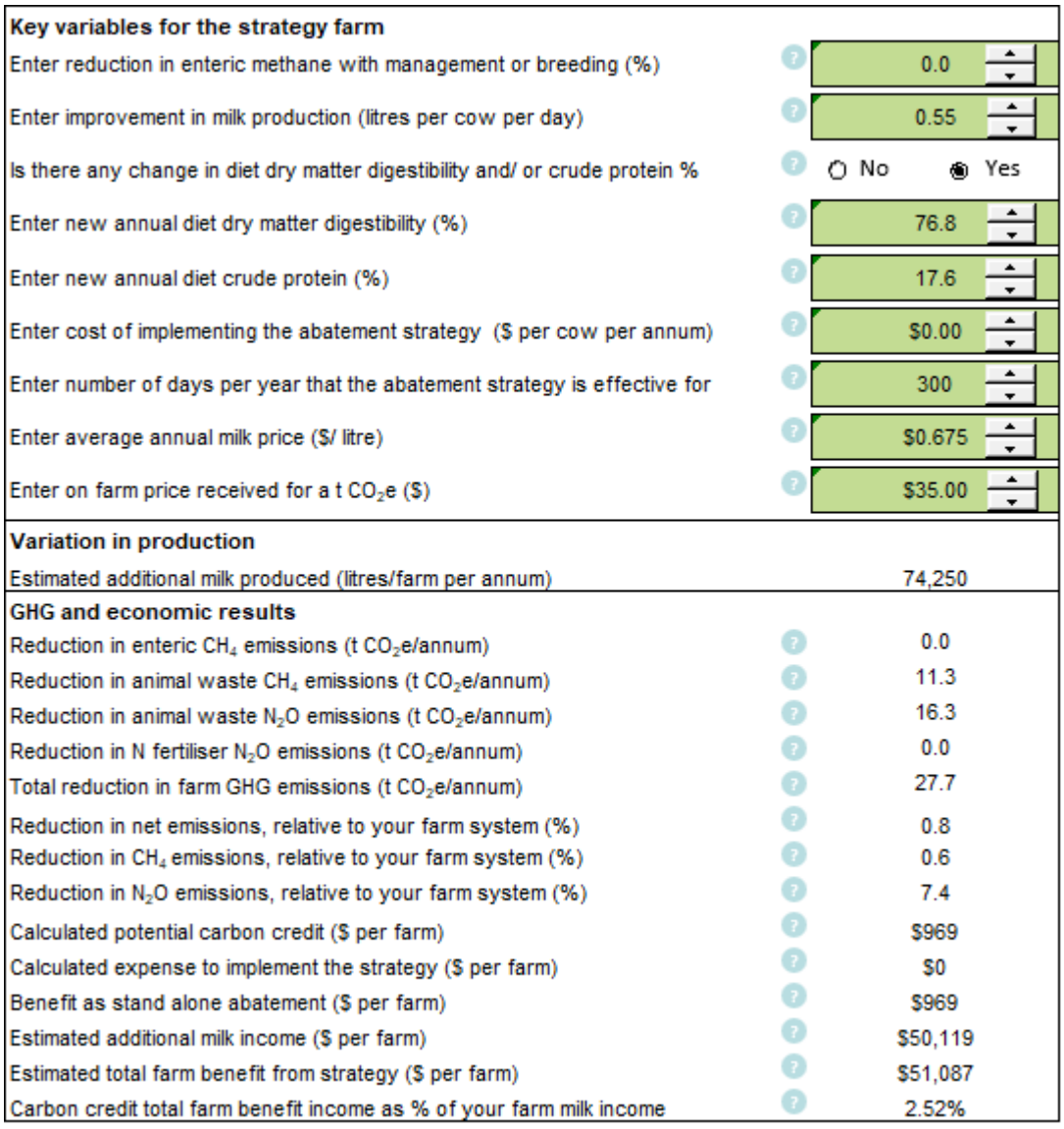
However, we need to consider that the high-sugar ryegrass does not constitute the whole diet and might not be grazed every day or be in every paddock. In this example, in the 'Your Farm' system pastures constitute 70% of the overall diet (12 kg DM of a 17 kg DM diet) so we keep this consistent here. Ryegrass constitutes 80% of the pasture sward (the balance being clovers etc) and the high-sugar ryegrass is only sown across 65% of the grazing platform. The net outcome is that DMD only increases by approx. 1.1% improvement in DMD% (i.e. 3% improvement in DMD x 70% pasture in diet x 80% ryegrass in the sward x 65% of the paddocks). This increased diet DMD% from 75.7% to 76.8% with the strategy.

If the whole diet was the new high-sugar ryegrass, milk production could increase by approx. 1.5 litres/day (i.e. 0.5 MJ ME x 17 kg DMI / 5.5 MJ ME per litre milk). However, like the change in DMD%, milk production also only increased by approx. one-third of this, equating to approx. 0.56 litres/day (i.e. 0.5 MJ ME x 17 kg DMI x 70% of the overall diet x 80% of the pastures is ryegrass x 65% of the paddocks have high-sugar ryegrass / 5.5 MJ ME per litre milk). To allow rapid increase or decrease with the use of the up/down arrows, milk production increases in increments of 0.05 litres so in this example, we rounded milk production down slightly to 0.55 litres per cow per day.

High sugar-ryegrasses have also been shown to reduce diet CP% (e.g. Cosgrove et al. (2009); Turner et al. (2015)). A similar process as used above for diet DMD% would need to be undertaken but for simplicity, we assumed a 1% decrease in diet CP%. We also assumed that there was no additional cost associated with this intervention, e.g. the high-sugar ryegrass seed is the same prices as standard ryegrass seed, and the pastures are not renovated any more frequently. If there was an additional price, this would need to be worked out on an annualised basis and divided by the number of milking cows to determine a cost per cow per annum.

As we have already considered that not all the farm has high-sugar ryegrass pastures, we can leave the abatement strategy being effective for 300 days so that the extra milk x 300 days x milking herd determines the additional milk production realised.

The milk price was set at \$0.675/litre, while the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was \$35/t CO_2e. Unlike in Figures 49 and 50, the strategy resulted in only producing an extra 74,250 litres of milk per annum. The diet was more digestible thus there was a reduction in waste CH_4 of 11.3 t CO_2e. The decline in overall diet CP along with more nitrogen being exported off farm with the increase in milk production resulted in a 16.3 t CO_2e decline in waste N_2O emissions, thus net farm emissions declined by 27.7 t CO_2e/annum. The annum total farm benefit was \$51,087, based on a carbon credit of \$969, an additional milk income of \$50,119 with no cost of implementation (Figure 66). The net change in farm income, relative to the 'Your farm' milk income, was estimated at 2.52% (Figure 66). In addition, the extra milk might require more electricity for milking and cooling, further reducing net profits as well as GHG emissions from electricity usage.



Key variables for the strategy farm	
Enter reduction in enteric methane with management or breeding (%)	0.0
Enter improvement in milk production (litres per cow per day)	0.55
Is there any change in diet dry matter digestibility and/ or crude protein %	○ No ◉ Yes
Enter new annual diet dry matter digestibility (%)	76.8
Enter new annual diet crude protein (%)	17.6
Enter cost of implementing the abatement strategy ($ per cow per annum)	$0.00
Enter number of days per year that the abatement strategy is effective for	300
Enter average annual milk price ($/ litre)	$0.675
Enter on farm price received for a t CO_2e ($)	$35.00
Variation in production	
Estimated additional milk produced (litres/farm per annum)	74,250
GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	0.0
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	11.3
Reduction in animal waste N_2O emissions (t CO_2e/annum)	16.3
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	27.7
Reduction in net emissions, relative to your farm system (%)	0.8
Reduction in CH_4 emissions, relative to your farm system (%)	0.6
Reduction in N_2O emissions, relative to your farm system (%)	7.4
Calculated potential carbon credit ($ per farm)	$969
Calculated expense to implement the strategy ($ per farm)	$0
Benefit as stand alone abatement ($ per farm)	$969
Estimated additional milk income ($ per farm)	$50,119
Estimated total farm benefit from strategy ($ per farm)	$51,087
Carbon credit total farm benefit income as % of your farm milk income	2.52%

Figure 66. Screenshot of the key variables, variation in production (milk production in this instance), and GHG and economic results of implementing a strategy to improve milk production through a management option that also reduced waste CH_4 and N_2O emissions.

8.2. Diet additives

This is a newly established intervention that has been asked for by industry and explores targeted feed additives, such as *Asparagopsis taxiformis* where the user must know some more specific data entry questions which is derived from scientific papers and research projects.

Key variables for the strategy farm

In addition to several questions asked for most interventions, this one requires:

- Feeding rate of feed additive- milligrams (mg) of active ingredient per kg of dry matter intake
- Reduction in enteric CH_4 emissions- grams of CH_4 reduced/kg active ingredient
- Cost of active ingredient- $/gram active ingredient (e.g. bromoform in the case of *Asparagopsis*)

How are the results of the strategy calculated?

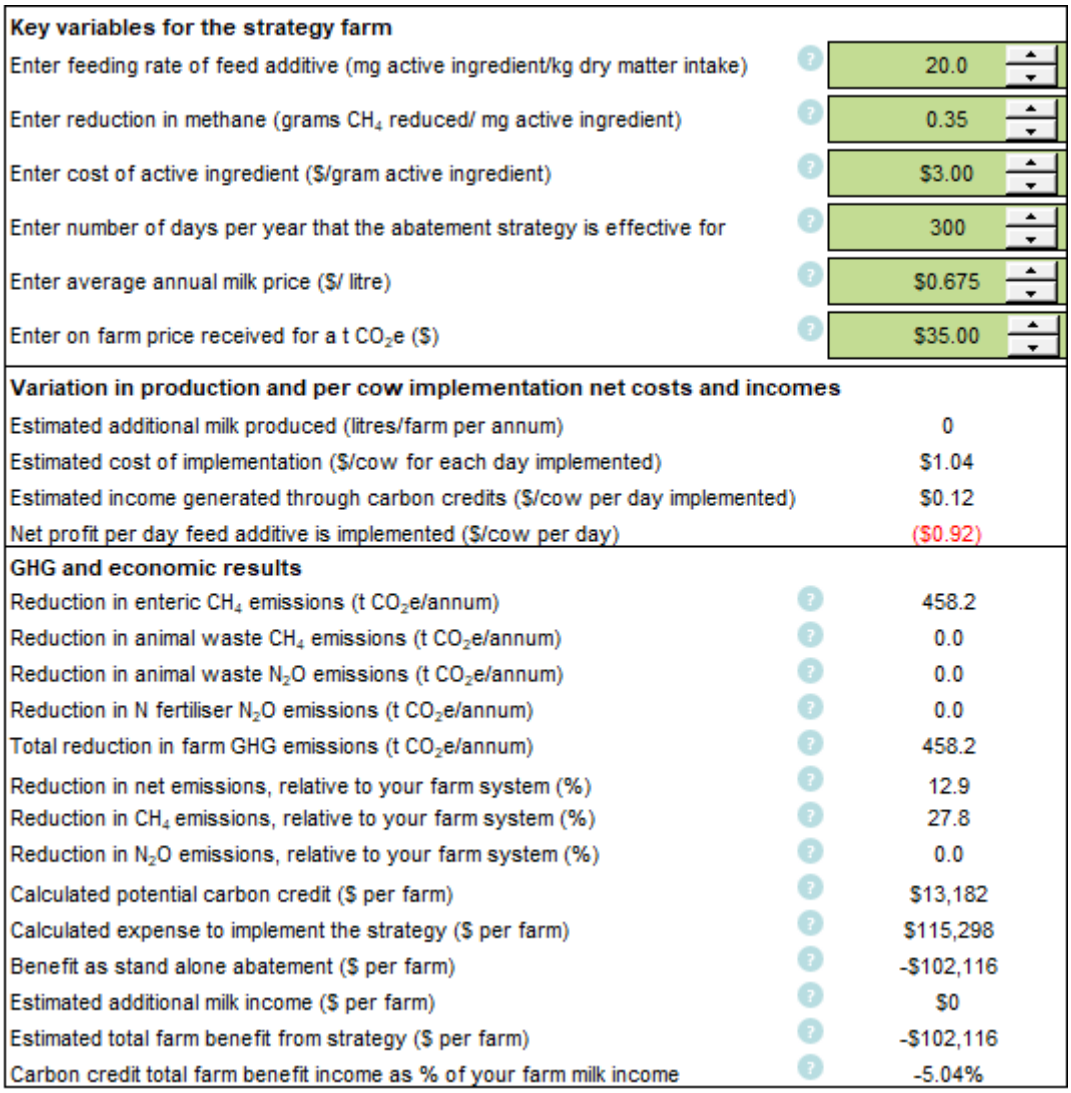
We have created a table with the mg of active ingredient/kg DMI ranging from 0 to 30. Enteric CH_4 emissions decrease by the rate of CH_4 reduction as determined by the user, thus if the rate of reduction was 0.35 g CH_4 reduction/mg active ingredient, and we fed 5 mg/kg DMI, then enteric CH_4 yield would reduce from 20.7 to 18.95 g CH_4/kg DMI. This is then multiplied by the daily intake, number of days the active ingredient is fed and then milking herd size to determine the intervention annual CH_4 emissions. The cost of implementation is estimated by determining the total daily rate of active ingredient fed per cow.day and multiplied by the cost, days fed and number of milking cows.

Within the third section, in addition to estimating changes in milk production (assumed to be zero with the current ADCC version but may be included in future interactions), the calculator also determines the estimated cost of implementation (excluding any additional costs such as needing the active ingredient to be blended with other feeds for delivering), and the estimated income generated through carbon credits to determine the net profit per head per day the feed additive is implemented. The help messages for this intervention reports results from a paper by Eason and Fennessey (2023) based on feeding *Asparagopsis* to cattle. Within ADCC, we have set an upper limit of 30 mg of active ingredient/kg DMI. If there was sound reasons for altering this upper limit, users could unprotect the tab and unhide the rows to locate the lookup table used for the analysis (starts at row 139).

Example of results

In this example below (Figure 67), we assumed a feeding rate of 20 mg of active ingredient/kg DMI which reduced enteric CH_4 by 0.35 grams/mg active ingredient. The cost was set at $3/ gram of active ingredient with only the milking cows fed over their 300 day location period. Note that we need to know the values for the active ingredient, bromoform in this example, as opposed to *Asparagopsis*. The milk price was set at $0.675/litre, while the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was $35/t CO_2e. ADCC estimated the cost was $1.04/cow.day while the generated income was only $0.12/cow.day thus a net decline in profit of $0.92/cow.day (shown in red). This is further shown in the results as the annum total farm benefit was -$102,116, based on a carbon credit of $13,182, no additional milk income and costing $115,298 to implement (Figure 67). The net change in farm income, relative to the 'Your farm' milk income, was estimated at -5.04% (Figure 67). In addition, if the cows were able to produce more milk, that extra milk might require more electricity for milking and cooling, further reducing net profits as well as GHG emissions from electricity usage.

While not shown here, using the up and down arrows showed for this intervention to be profitable, the cost of implementation would need to be as low as $0.35/cow.day if all other assumptions remained as listed above, e.g. enteric CH_4 remained at 0.35 g CH_4 reduction/ mg active ingredient. Alternatively, if the active ingredient remained at $3/gram, the price for each t of CO2e removed would need to be > $300/ t CO_2e.



Key variables for the strategy farm	
Enter feeding rate of feed additive (mg active ingredient/kg dry matter intake)	20.0
Enter reduction in methane (grams CH_4 reduced/ mg active ingredient)	0.35
Enter cost of active ingredient ($/gram active ingredient)	$3.00
Enter number of days per year that the abatement strategy is effective for	300
Enter average annual milk price ($/ litre)	$0.675
Enter on farm price received for a t CO_2e ($)	$35.00
Variation in production and per cow implementation net costs and incomes	
Estimated additional milk produced (litres/farm per annum)	0
Estimated cost of implementation ($/cow for each day implemented)	$1.04
Estimated income generated through carbon credits ($/cow per day implemented)	$0.12
Net profit per day feed additive is implemented ($/cow per day)	($0.92)
GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	458.2
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	0.0
Reduction in animal waste N_2O emissions (t CO_2e/annum)	0.0
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	458.2
Reduction in net emissions, relative to your farm system (%)	12.9
Reduction in CH_4 emissions, relative to your farm system (%)	27.8
Reduction in N_2O emissions, relative to your farm system (%)	0.0
Calculated potential carbon credit ($ per farm)	$13,182
Calculated expense to implement the strategy ($ per farm)	$115,298
Benefit as stand alone abatement ($ per farm)	-$102,116
Estimated additional milk income ($ per farm)	$0
Estimated total farm benefit from strategy ($ per farm)	-$102,116
Carbon credit total farm benefit income as % of your farm milk income	-5.04%

Figure 67. Screenshot of the key variables, variation in production (milk production, cost, income, and net profit per cow per day in this instance), and GHG and economic results of implementing a strategy of feeding an additive to reduce enteric CH_4 emissions.

8.3. Extended lactation to reduce enteric methane production

This strategy explores the impact of an extended lactation for the milking herd in terms of changes in enteric CH_4 emissions and milk production. This strategy did not explore any potential reduction in the number of replacement heifers required. In addition, there is no review of changes in N_2O emissions due to manure management or changes in electricity consumption, as the cows spend a greater proportion of their lifetime being milked.

An example of an extended lactation may be that instead of a cow having six lactations, calving every year, the cow now has four lactations, and they calve every 18 months. Both examples have cows remaining on the farm for the same duration. However, the latter extended lactation option has them producing milk for a greater proportion of their lifetime.

Key variables for the strategy farm

Unlike all other adaptation strategies, the user needs to fill in some components of the 'Your Farm' data within the green box area. Users need to enter daily milk production for the 1st lactation cows, mature cows, and the number of lactations before culling (Figure 68). In this example below, the 1st lactation cows gave an average of 21 litres/day over their 300 day lactation, the mature cows gave 23 litres/day over their 300 day lactation and the average number of lactations was 6 prior to culling.

Your farm system data relevant to this abatement strategy	
Your farm number of milkers	450
Average liveweight of mature milking cow (kg)	500
Average daily milk production during the 1st lactation (litres/cow.day)	21.0
Average daily milk production during subsequent lactations (litres/cow.day)	23.0
Average lactation length (days)	300
Average number of lactations before culling	6

Figure 68. Screenshot of the additional 'Your Farm' system data required for the Extended lactation abatement strategy.

Users must enter the calving date in the Key variables section (in dd/mm/yyyy format) for the start of lactation comparison, daily milk production for the first and subsequent lactation cows (can be different to the baseline 'Your farm' cows), length of lactation, length of dry period between lactations, number of lactations before culling, any costs associated with implementing an extended lactation, as well as the average annual milk price, and on-farm price received for a tonne of CO_2e (Figure 69).

How are the results of the strategy calculated?

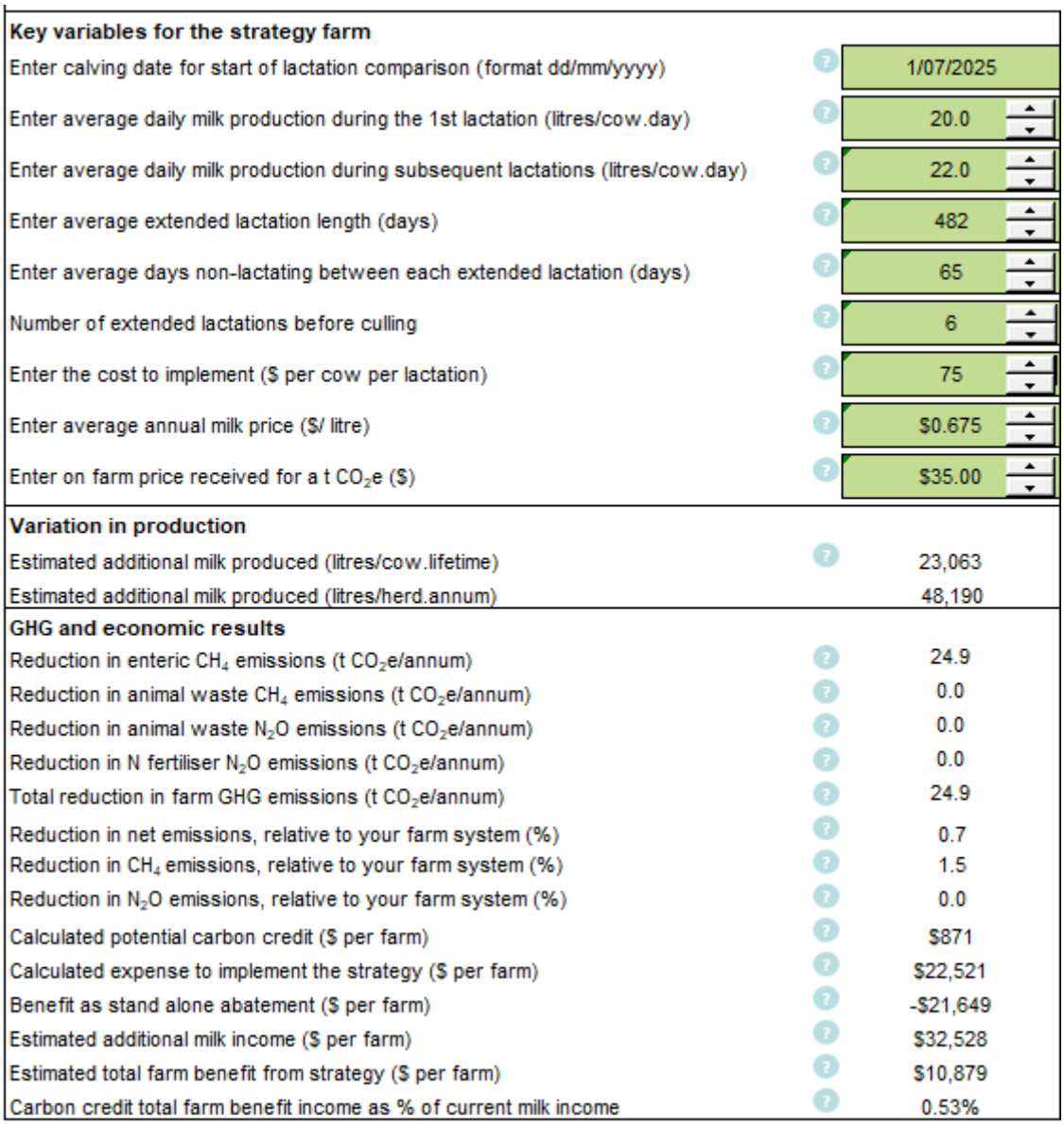
This abatement option has the most difficult calculations to determine the effect of extended lactation on net GHG emissions. Essentially, the energy required for maintenance, growth during the first lactation, pregnancy, and milk production is compared between cows calving every 12 months to those calving less frequently.

Example of results

In the example below (Figure 69), the comparison commenced 1/7/2025 for the 'Your Farm' cows milked for 300 days vs the 'Strategy Farm' cows milked for 482 days, while dry for 65 days (the same number of days dry between lactations as per the 'Your Farm' system). The extended lactation cows produce more milk per lifetime but less per day over the duration of their lactations. In this example, the extended lactation 1st lactation cows produced 20 litres/day, and the subsequent lactation cows produced 22 litres/day. The cows were retained to a similar age before culling, resulting in 4 lactations over a lifetime vs 6 lactations with the 'Your Farm'. The user needs to ascertain how costs might alter with this strategy. For example, there are lower breeding costs as the cows are only bred 4 times vs 6 times, but they are spending more time milking so the farm may require additional supplementary grain or additional electricity during milk harvesting. In this example, it was estimated to cost an additional $75/lactation compared to their baseline counterparts. The milk price was set at $0.675/litre, while the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was $35/t CO_2e.

As the strategy farm system resulted in cows spending a greater proportion of their lifetime producing milk, and thus intakes were greater, this abatement strategy resulted in a minimal reduction in enteric CH_4 emissions. Note that COST does not consider any reduction in the number of replacement heifers required, which would further reduce net GHG emissions. Total farm benefit was $10,879, based on a carbon credit of $871, an additional milk income of $32,528, and an implementation cost of $22,521 (Figure 69). The net change in farm income, relative to the 'Your farm' milk income, was estimated at 0.53% (Figure 69). Although not taken into consideration here, the extra milk might require more electricity for milk harvesting and cooling, further reducing net profits as well as increasing GHG emissions from electricity usage.

In this example, a quick use of the up/down arrows in the Key variables section illustrated that if the additional cost to implement was greater than ~ $110/cow, the cost of implementation would erode any additional income from milk, thus resulting in a reduction of total farm benefit (not shown here). Extending lactations from 10 to 16 months, to reflect calving every 18 months, as opposed to 22 months, reflecting calving every 2 years, could result in a different outcome than presented here.



Key variables for the strategy farm	
Enter calving date for start of lactation comparison (format dd/mm/yyyy)	1/07/2025
Enter average daily milk production during the 1st lactation (litres/cow.day)	20.0
Enter average daily milk production during subsequent lactations (litres/cow.day)	22.0
Enter average extended lactation length (days)	482
Enter average days non-lactating between each extended lactation (days)	65
Number of extended lactations before culling	6
Enter the cost to implement ($ per cow per lactation)	75
Enter average annual milk price ($/ litre)	$0.675
Enter on farm price received for a t CO_2e ($)	$35.00
Variation in production	
Estimated additional milk produced (litres/cow.lifetime)	23,063
Estimated additional milk produced (litres/herd.annum)	48,190
GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	24.9
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	0.0
Reduction in animal waste N_2O emissions (t CO_2e/annum)	0.0
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	24.9
Reduction in net emissions, relative to your farm system (%)	0.7
Reduction in CH_4 emissions, relative to your farm system (%)	1.5
Reduction in N_2O emissions, relative to your farm system (%)	0.0
Calculated potential carbon credit ($ per farm)	$871
Calculated expense to implement the strategy ($ per farm)	$22,521
Benefit as stand alone abatement ($ per farm)	-$21,649
Estimated additional milk income ($ per farm)	$32,528
Estimated total farm benefit from strategy ($ per farm)	$10,879
Carbon credit total farm benefit income as % of current milk income	0.53%

Figure 69. Screenshot of the key variables, variation in production (milk production in this instance), and GHG and economic results of implementing a strategy of extended lactations to reduce enteric CH_4 emissions.

8.4. Extended longevity to reduce replacement rates

This strategy explores the impact of reducing the replacement rate, and thus retaining fewer heifers each year, to reduce net GHG emissions. It is assumed that these non-replacement heifers exit the farm post-weaning. This strategy does not consider other aspects, such as any impact on generic improvement within the herd. Unlike several other strategies, this one does take into consideration changes in enteric CH_4, waste CH_4, and N_2O emissions.

Key variables for the strategy farm

There are several questions in the Key variables section asking how many heifers are now retained in the two age groups, the cost of raising a heifer calf to the point of calving, as well as the average annual milk price, and on-farm price received for a tonne of CO_2e (Figure 70).

How are the results of the strategy calculated?

The only change in this strategy is a decrease in the number of heifers, so the equations to estimate GHG emissions remain the same as per the 'Your Farm' system.

Example of results

In the example below (Figure 70), the 'Your Farm' system retained 120 Rising 2 year old heifers, which when we divide the number of milkers by the number of heifers entering the herd, we get the milkers remaining on farm for 3.75 lactations on average. If we extended this to cows remaining on farm for an average of 4.25 lactations, this means we would only need to retain ~ 105 Rising 2 yr olds and 110 Rising 1 year olds, reducing the number of heifers retained each year by around 15 head per age group. This resulted in the herd replacement rate declining from 27 to 23% (shown in the Variation in production section below in Figure 70). The cost to raise a heifer to the point of calving was estimated at $2,200/head. The milk price was set $0.675/litre, while the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was $35/t CO_2e.

Total GHG emissions were reduced by 39.3 t CO_2e/annum. Total farm benefit was $34,376, based on a carbon credit of $1,376, and a savings of $33,000 per annum because we were no longer raising an additional 15 heifers per age group each year, coupled with no change in herd milk production (Figure 70). The net change in farm income, relative to the 'Your farm' milk income, was estimated at 1.7% (Figure 70).

In this example, we have not assumed any other changes to the system. For example, the pastures no longer consumed by heifers could be conserved into supplementary feed, reducing reliance on purchased feed with associated Scope 3 GHG emissions, the milkers could consume the extra pasture directly, potentially increasing their milk production which would increase their emissions, or the slowing down genetic improvement in the herd could also result in GHG-related implications.

Key variables for the strategy farm		
Enter number of heifers > 1 yr age		105
Enter number of heifers < 1 yr age		110
Enter the price to raise a heifer calf to the point of joining the milking herd ($/head)		2,200
Enter average annual milk price ($/ litre)		$0.675
Enter on farm price received for a t CO_2e ($)		$35.00
Variation in production		
Estimated your farm replacement rate		27%
Estimated strategy replacement rate		23%
GHG and economic results		
Reduction in enteric CH_4 emissions (t CO_2e/annum)		33.4
Reduction in animal waste CH_4 emissions (t CO_2e/annum)		0.7
Reduction in animal waste N_2O emissions (t CO_2e/annum)		5.2
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)		0.0
Total reduction in farm GHG emissions (t CO_2e/annum)		39.3
Reduction in net emissions, relative to your farm system (%)		1.1
Reduction in CH_4 emissions, relative to your farm system (%)		12.3
Reduction in N_2O emissions, relative to your farm system (%)		12.3
Calculated potential carbon credit ($ per farm)		$1,376
Calculated expense to implement the strategy ($ per farm)		-$33,000
Benefit as stand alone abatement ($ per farm)		$34,376
Estimated additional milk income ($ per farm)		$0
Estimated total farm benefit from strategy ($ per farm)		$34,376
Carbon credit total farm benefit income as % of current milk income		1.70%

Figure 70. Screenshot of the key variables, variation in production (comparison of replacement rate in this instance), and GHG and economic results of implementing a strategy of reducing the replacement rate to reduce all animal-related GHG emissions.

8.5. Replacing supplements in the diet with a source of dietary fats/oils

This strategy explores the impact of feeding dietary fats (ether extract) in the diet in terms of reducing enteric CH_4 emissions. It has been shown that enteric CH_4 emissions can be reduced by 3.5% for each 1% increase in dietary fat in the overall diet (Moate *et al.* 2016). Examples of supplements with high dietary fat include canola meal, brewer's grain, dried distiller's grain, hominy meal, and grape marc. There is an upper limit (6-7%) on how much dietary fat can be in cow's diets before milk suppression occurs. Please seek expert advice before implementing this strategy on farm.

The fat content of pastures in winter and spring is generally 4-5%, so little scope to increase the overall fat content of the diet. However, over summer and autumn, rainfed pastures can be as low as 2-3%. Feeding a source of dietary fat could also supply additional energy, increasing milk production in addition to reducing CH_4 emissions. This strategy assumes that an amount of baseline 'Your farm' supplement is replaced with the same amount of high dietary fat supplement, for example, reducing silage feeding by 2 kg DM/day, and replaced with canola meal at the same rate of 2 kg DM/day. If you want to feed an additional high-fat supplement above that which is being replaced, use the Supplementing with dietary fats strategy tab (section 8.6).

Key variables for the strategy farm

There are many questions in the Key variables section to ascertain (Figure 71). Firstly, the fat content of the 'Your farm' diet is not captured during the data entry period for the 'Your Farm', thus this needs to be determined. Users will need to access likely fat contents from other sources. Examples include:

- feed tests of your current pastures,
- local agronomists or consultants,
- searching the internet (e.g. see Moss (2020) https://agrifutures.com.au/wp-content/uploads/2020/09/20-078.pdf for common grain and by-products or accessing https://www.feedipedia.org/node for some common feed sources),
- talking to Dairy Australia extension staff, or
- use the examples above for pastures (4-5% in winter and spring or year-round for irrigated pastures, 2-3% for rainfed summer and autumn pastures)

Other questions relate to the fat%, DMD%, and CP% of the dietary fat, the amount of 'Your farm' supplement replaced with a high dietary fat supplement, the costs of the 'Your farm' and dietary fat supplements, the number of days per annum the dietary fat is fed, as well as the average annual milk price, and on-farm price received for a tonne of CO_2e (Figure 71).

How are the results of the strategy calculated?

The feeding of dietary fats used to be an ERF method project. However, the sunset clause of 10 years has meant that this strategy is no longer available to implement on farm. However, for consistency, we have retained the method as per the ERF project.

The method used in ADCC does not consider dietary fat percentages to estimate the 'Your Farm' enteric CH_4. Thus, for this strategy, COST re-estimates the 'Your Farm' enteric CH_4 emissions, and compares this to the strategy farm enteric CH_4 emissions, both following the ERF project methodology. Enteric CH_4 (g CH_4/kg DMI) is calculated as 24.51 – 0.0788 x dietary fat % of the overall diet (Moate *et al.* 2011). Changes in the diet's energy content are considered to estimate any additional energy available for milk production, assuming 5.5 MJ of metabolisable energy (ME) per litre of milk.

To align with the ERF methodology, if the digestibility of the new overall diet declines, waste CH_4 emissions will increase. However, the ERF project methodology does not recognise that an increase in overall diet DMD should allow for a reduction in waste CH_4 emissions. Likewise, if the CP of the new overall diet increases, waste N_2O emissions will also increase. However, the methodology does not recognise a decrease in overall diet CP which should allow for a reduction in waste N_2O emissions.

Example of results

In the example below (Figure 71), we have replaced 4kg DM of silage per day with the same amount of high-fat supplement fed in the dairy for 150 days over the summer/autumn period. The 'Your farm' fat content of the overall diet was 4%, and the inclusion of the high-fat supplement increased the overall diet fat content to 5.62% (first row in the middle section of Figure 71). The high-fat supplement was higher in DMD (80% vs 72% for the silage), thus milk production increased by ~ 59,700 litres over the summer/autumn period. The high-fat supplement was lower in CP (12% vs 17% for the silage), costing an additional $50/t DM compared with the silage it was replacing. The milk price was set at $0.675/litre, while the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was $35/t CO_2e. If the feeding of the high-fat supplement in summer and autumn occurred during a time of the year when milk prices were above the long-term average, this could be incorporated into the estimate of additional milk income by changing the milk price for when the supplement was fed. Enteric CH_4 emissions declined by 32.3 t CO_2e/annum. Total farm benefit was $27,911, based on a carbon credit of $1,130, an additional milk income of $40,281, and an implementation cost of $13,500 (Figure 71). The net change in farm income, relative to the 'Your farm' milk income, was estimated at 1.38% (Figure 71). Although not taken into consideration here, the extra milk might require more electricity for milk harvesting and cooling, further reducing net profits as well as increasing GHG emissions from electricity usage.

Key variables for the strategy farm	
Enter estimated fat content of your farm diet (%)	4.0
Enter amount of your farm supplement to be replaced (kg DM/cow.day)	4.0
Enter digestibility of your farm supplement to be replaced (%)	72.0
Enter crude protein of your farm supplement to be replaced (%)	17.0
Enter fat content of your farm supplement to be replaced (%)	3.0
Enter cost of your farm supplement to be replaced ($/t DM)	300
Enter digestibility of the new abatement strategy supplement (%)	80.0
Enter crude protein of the new abatement strategy supplement (%)	12.0
Enter fat content of the new abatement strategy supplement (%)	10.0
Enter cost of new abatement strategy supplement ($/t DM)	350
Enter number of days per year the new abatement supplement is fed	150
Enter average annual milk price ($/ litre)	$0.675
Enter milk price for when supplements fed ($/litre)	$0.675
Enter on farm price received for a t CO_2e ($)	$35.00
Variation in production	
Estimated fat content in the abatement strategy diet during the activation peri	5.62
Estimated additional milk produced (litres/farm)	59,676
GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	32.3
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	0.0
Reduction in animal waste N_2O emissions (t CO_2e/annum)	0.0
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	32.3
Reduction in net emissions, relative to your farm system (%)	0.9
Reduction in CH_4 emissions, relative to your farm system (%)	1.7
Reduction in N_2O emissions, relative to your farm system (%)	0.0
Calculated potential carbon credit ($ per farm)	$1,130
Calculated expense to implement the strategy ($ per farm)	$13,500
Benefit as stand alone abatement ($ per farm)	-$12,370
Estimated additional milk income ($ per farm)	$40,281
Estimated total farm benefit from strategy ($ per farm)	$27,911
Carbon credit total farm benefit income as % of current milk income	1.38%

Figure 71. Screenshot of the key variables, variation in production (estimated fat content of the strategy diet and change in milk production in this example), and GHG and economic results of implementing a strategy of feeding dietary fats to the milking herd over summer and autumn.

8.6. Increase diet supplementation with a source of dietary fats/oils

This strategy explores the impact of feeding a supplement high in dietary fats (ether extract) in terms of reducing enteric CH_4 emissions. This strategy differs to the previous one (section 8.5) in that here, we assume an increase in supplementary feeding to increase overall dietary intake.

It has been shown enteric CH_4 emissions can be reduced by 3.5% for each 1% increase in dietary fat in the overall diet (Moate *et al.* 2016). Examples of supplements with high dietary fat include canola meal, brewer's grain, dried distiller's grain, hominy meal, and grape marc. There is an upper limit (6-7%) on how much dietary fat can be in cow's diets before milk suppression occurs. Please seek expert advice before implementing this strategy on farm.

The fat content of pastures in winter and spring is generally 4-5%. However, over summer and autumn, rainfed pastures can be as low as 2-3%. Therefore, unlike the previous strategy, this one assumes extra supplementation will increase milk production, reduce enteric CH_4 emissions, and potentially alter waste CH_4 and N_2O emissions, depending on overall diet quality changes.

Key variables for the strategy farm

There are many questions in the Key variables section to ascertain (Figure 72). Firstly, the fat content of the baseline 'Your farm' diet is not captured during the data entry period for the 'Your Farm', thus this needs to be determined. Users will need to access likely fat contents from other sources. Examples include:

- feed tests of your current pastures,
- local agronomists or consultants,
- searching the internet (e.g. see Moss (2020) https://agrifutures.com.au/wp-content/uploads/2020/09/20-078.pdf for common grain and by-products or accessing https://www.feedipedia.org/node for some common feed sources),
- talking to Dairy Australia extension staff, or
- use the examples above for pastures (4-5% in winter and spring or year-round for irrigated pastures, 2-3% for rainfed summer and autumn pastures)

Other questions relate to the fat%, DMD%, and CP% of the dietary fat, the number of days per annum the dietary fat is fed, the potential substitution rate (0-1), the cost of the dietary fat supplements, as well as the average annual milk price, and on-farm price received for a tonne of CO_2e (Figure 72).

How are the results of the strategy calculated?

Unlike the previous section 8.5, this strategy retains the same methodology for estimating GHG emissions as per the 'Your Farm' system. The calculator determines the new diet quality parameters to estimate CH_4 and N_2O emissions using the substitution rate, and the new high-fat supplements fat%, DMD%, and CP%. A substitution rate of 0 means the cows are not fully fed, their intake from pasture and other supplements is not restricted, meaning they can eat more supplement without reducing intakes from other supplements and pastures. Therefore, they go from eating 14 kg DM/day to 16 kg DM/day with an additional 2 kg DM of high-fat supplement. In contrast, a substitution rate of 1 means the cows are fully fed, meaning that 1 kg of high-fat supplement replaces 1 kg DM/day of the 'Your farm' diet. Changes in the diet's energy content are considered to estimate any additional energy available for milk production, assuming 5.5 MJ of metabolisable energy (ME) per litre of milk.

This strategy does not follow the same guidelines as the ERF/CSF methodology as shown in section 8.5. Therefore, if the overall diet DMD% improves with the new high-fat supplement, this can reduce waste CH_4 emissions and is included in the net change in GHG emissions. If the CP% of the new higher fat diet decreases, so too will N_2O emissions. Conversely, if the new higher fat diet is higher in CP% than the 'Your farm' diet, N_2O emissions will increase accordingly.

Example of results

In the example below (Figure 72), we fed an extra 2 kg DM of a high-fat supplement in the dairy for 150 days over summer and autumn. We knew there was scope to increase overall diet intake, so assumed a substitution rate of 80%. The extra 2 kg of high-fat supplement resulted in the cows substituting 1.6 kg DM of 'Your farm' diet (i.e. 2 kg DM x 0.8 = 1.6 kg DM) with the high-fat supplement. For example, if the 'Your Farm' system cows were consuming 15 kg DM/day, they now consume 13.4 kg DM/day of the 'Your farm' diet, and 2.0 kg DM/day of the high-fat supplement, to that intake increased slightly to 15.4 kg DM/day. The calculator does not determine which component of the 'Your farm' diet is no longer consumed, although this is likely to be pasture which is substituted for the high-fat supplement. As the substitution rate increases, more of the 'Your farm' diet is no longer consumed, hence users need to ascertain how they may manage this 'wasted' feed, especially given it is most likely going to be grazed pastures.

The 'Your farm' fat content of the overall diet was 4%, and the inclusion of the high-fat supplement (13% fat) increased the overall diet fat content from 4.0 to 5.02%. The high-fat supplement was higher in DMD (80% vs 76% for the 'Your farm' diet), which led to an increase in milk production increased of ~ 89,500 litres over the summer/autumn period. The high-fat supplement was also lower in CP (12% vs 18.6% for the 'Your farm' diet) and cost $350/t DM. The milk price was set at $0.675/litre, and the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was $35/t CO_2e. Suppose the feeding of the high-fat supplement in summer and autumn occurred during a time of the year when milk prices were above the long-term average. In that case, this can be incorporated into the estimate of additional milk income by changing the milk price for when the supplement is fed. Total farm GHG emissions were reduced by 14.0 t CO_2e/annum, due to a reduction in enteric CH_4 emissions, and N_2O emissions to a lesser extent. While the diet DMD% increased, so too did intakes and milk production, thus increasing waste CH_4 production. Total farm benefit was $13,633, based on a carbon credit of $489, an additional milk income of $60,394, and an implementation cost of $47,250 (Figure 72). The net change in farm income, relative to the 'Your farm' milk income, was estimated at 0.76% (Figure 72). Although not taken into consideration here, the extra milk might require more electricity for milk harvesting and cooling, further reducing net profits as well as increasing GHG emissions from electricity usage.

Key variables for the strategy farm	
Enter estimated fat content of the current your farm diet (%)	4.0
Enter amount of additional supplement to be fed (kg DM/cow.day)	2.0
Enter digestibility of the additional supplement fed (%)	80.0
Enter crude protein of the additional supplement fed (%)	12.0
Enter estimated fat content of the supplement fed (%)	13.0
Enter number of days the fat source is fed (days/year)	150
Enter cost of additional supplementary feed ($/t DM)	350
Enter estimated substitution rate (range between 0 and 1)	0.80
Enter average annual milk price ($/ litre)	$0.675
Enter milk price for when supplements fed ($/litre)	$0.675
Enter on farm price received for a t CO_2e ($)	$35.00
Variation in production	
Estimated fat content of the abatement strategy diet (%)	5.02
Estimated additional milk produced (litres/farm)	89,473
GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	11.3
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	-0.3
Reduction in animal waste N_2O emissions (t CO_2e/annum)	3.0
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	14.0
Reduction in net emissions, relative to your farm system (%)	0.4
Reduction in CH_4 emissions, relative to your farm farm system (%)	0.6
Reduction in N_2O emissions, relative to your farm farm system (%)	1.3
Calculated potential carbon credit ($ per farm)	$489
Calculated expense to implement the strategy ($ per farm)	$47,250
Benefit as stand alone abatement ($ per farm)	-$46,761
Estimated additional milk income ($ per farm)	$60,394
Estimated total farm benefit from strategy ($ per farm)	$13,633
Carbon credit total farm benefit income as % of current milk income	0.67%

Figure 72. Screenshot of the key variables, variation in production (estimated fat content of the strategy diet and change in milk production in this example), and GHG and economic results of implementing a strategy of feeding dietary fats to the milking cow to alter CH_4 and N_2O emissions.

8.7. Improved diet digestibility to protein ratio through management

This strategy explores the effect of balancing the energy to protein ratio of the diet through management options in terms of reducing enteric CH_4, along with waste CH_4 and N_2O emissions. The diet of milking cows can be higher in protein than the 16-18% required, especially for farms with a higher proportion of grazed pasture in the diet (Rugoho *et al.* 2017; Christie *et al.* 2018). High protein diets require additional energy to remove excess urea, thus reducing the energy available for milk production. Excess protein in the diet also increases urinary N concentrations, thus increasing N_2O losses to the environment (Christie *et al.* 2014; Smith *et al.* 2021). Improving the energy to protein ratio of the diet is generally better achieved by reducing the CP% of the diet, although can also be achieved by increasing the DMD%. This strategy explores non-dietary changes, such as better grazing management, altered pasture species (e.g. high sugar ryegrasses; Turner *et al.* 2015), and irrigation infrastructure. We do not stipulate how the overall diet energy to protein ratio is achieved here. Section 8.8 explores DMD to CP ratio changes through supplementary feeding options.

Key variables for the strategy farm

The Key variables section questions relate to establishing the change in diet quality, the duration of the year the change occurs over, the costs associated with improving the energy to protein ratio of the diet, as well as the average annual milk price, and on-farm price received for a tonne of CO_2e (Figure 73). Note the cost of achieving an improved DMD to CP ratio is an annual cost. If the management option was better grazing management, this might not incur any additional genuine cost. However, if it were achieved through increased irrigation to improve diet DMD%, you may need to consider dividing the capital cost over many years or consider only including annual operational costs (i.e. electricity).

How are the results of the strategy calculated?

Altering the DMD and CP% of the milking cow's diet for the duration identified will alter the year-round diet DMD and CP% accordingly. Changes in the diet's energy content are taken into consideration to estimate any additional energy available for milk production, assuming 5.5 MJ of metabolisable energy (ME) per litre of milk. Conversely, if the energy content of the diet decreases, the calculator estimates a reduction in milk production. While reducing the CP of the diet may result in a reduction in the energy required to excrete the excess protein, we have not included this additional energy available for milk production in the estimations here.

Example of results

In the example below (Figure 73), we assumed the intervention was a combination of better grazing management but also included renovating several paddocks each year with a high sugar ryegrass with a higher ME to CP ratio, in part due to a lower CP%. Diet DMD increased by 2% to 78%, while CP declined by 1.6% to 17% and this was implemented for the full 12 month period. The 'Your farm' DMD to CP ratio was 4.1 while the strategy ratio increased to 4.6. Better grazing management did not incur any additional costs. However, renovating the paddocks was assumed to incur an additional $5,000/annum above 'Your farm' annual renovating costs. The milk price was set at $0.675/litre, and the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was $35/t CO_2e. In this example, enteric CH_4 emissions increased (i.e. a negative reduction in enteric CH_4 value) due to increased milk production assuming an increase in intake. However, waste CH_4 emissions declined due to improved diet digestibility. Waste N_2O emissions also declined as there was less N excreted in urine, resulting in a net reduction in total GHG emissions of 25.7 t CO_2e/annum. Total farm benefit was $171,782, based on a carbon credit of $899, an additional milk income of $175,883, and an implementation cost of $5,000 (Figure 73). The net change in farm income, relative to the 'Your farm' milk income, was 8.48% (Figure 73).

Although not taken into consideration here, the extra milk might require more electricity for milk harvesting and cooling, further reducing net profits as well as increasing GHG emissions from electricity usage. We also did not assume any additional tractor usage to renovate the pastures, as this too would have increased Scope 3 emissions from fuel usage.

Key variables for the strategy farm	
Enter digestibility of the abatement strategy diet (%)	78.0
Enter crude protein of the abatement strategy diet (%)	17.0
Enter time period of improved diet digestibility (number of days per year)	365
Enter cost of achieving improved diet digestibility to protein ratio ($/ annum)	$5,000
Enter average annual milk price ($/ litre)	$0.675
Enter milk price for when increased diet DMD is available ($/ litre)	$0.675
Enter on farm price received for a t CO_2e ($)	$35.00
Variation in production	
Estimated change in daily diet energy (MJ/cow.day)	8.73
Estimated additional milk produced (litres/farm per annum)	260,568
GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	-20.2
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	20.7
Reduction in animal waste N_2O emissions (t CO_2e/annum)	25.2
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	25.7
Reduction in net emissions, relative to your farm system (%)	0.7
Reduction in CH_4 emissions, relative to your farm system (%)	0.0
Reduction in N_2O emissions, relative to your farm system (%)	11.3
Calculated potential carbon credit ($ per farm)	$899
Calculated expense to implement the strategy ($ per farm)	$5,000
Benefit as stand alone abatement ($ per farm)	-$4,101
Estimated additional milk income ($ per farm)	$175,883
Estimated total farm benefit from strategy ($ per farm)	$171,782
Carbon credit total farm benefit income as % of current milk income	8.48%

Figure 73. Screenshot of the key variables, variation in production (estimated change in daily diet energy intakes and change in milk production in this example), and GHG and economic results of implementing a management option strategy of improving the diet's dry matter digestibility to crude protein ratio for the milking cow to alter CH_4 and N_2O emissions.

8.8. Improved diet digestibility to protein ratio through supplementary feed

This strategy explored the effect of balancing the diet of the milking cow through supplementary feeding in terms of reducing enteric CH_4, along with waste CH_4 and N_2O emissions. Other strategies, such as section 8.7 explored other management options to improve the DMD to CP ratio of the diet, whereas sections 8.5 and 8.6 focused on higher dietary fat supplements. In this section, we assumed no material difference in the dietary fat content of the diet.

The diet of milking cows is generally higher in protein than the 16-18% required, especially for farms with a higher proportion of grazed pasture in the diet (Rugoho *et al.* 2017; Christie *et al.* 2018). High protein diets require additional energy to remove excess urea, thus reducing energy available for milk production. Excess protein in the diet also increases urinary N concentrations, thus increasing N_2O losses to the environment (Christie *et al.* 2014; Smith *et al.* 2021). Improving the energy to protein ratio of the diet is generally better achieved by reducing the CP% of the diet, although it can also be achieved by increasing the DMD%.

Key variables for the strategy farm

The Key variables section questions relate to the amount of additional supplement fed, along with the substitution rate (0-1), the DMD%, CP%, and cost of the new supplement, the number of days per annum the supplement is fed, as well as the average annual milk price, and on-farm price received for a tonne of CO_2e (Figure 74).

How are the results of the strategy calculated?

Altering the DMD and CP% of the milking cow's diet for the duration identified, along with the substitution rate, will alter the year-round diet DMD and CP% accordingly. The calculations here remain the same as per the 'Your Farm' system, by altering the DMD and CP% of the milking cow's diet for the duration identified, considering the substitution rate throughout the period of feeding. A substitution rate of 0 means the cows are not fully fed, and thus their intake from pasture and other supplements is not restricted; they go from eating 14 kg DM/day to 16 kg DM/day with an additional 2 kg DM of new supplement. In contrast, a substitution rate of 1 means the cows are fully fed so that 1 kg DM of new supplement means the cows are no longer consume 1 kg DM of the 'Your farm' diet. Changes in the diet's energy content are taken into consideration to estimate any additional energy available for milk production, assuming each litre of milk requires 5.5 MJ of metabolisable energy. Conversely, if the energy content of the diet decreases, the calculator estimates a reduction in milk production. While reducing the CP of the diet will generally result in a reduction in the energy required to excrete the excess protein, and thus be available for additional milk production, we have not included this in the estimations here.

Example of results

In the example below (Figure 74), we increased grain feeding by an extra 2 kg DM/day, with the grain having a DMD of 82% and CP of 12%. The extra grain was fed over 150 days per annum (summer and autumn) with a 1.0 substitution rate (i.e. we replaced 2 kg DM of silage with 2 kg DM of grain). The 'Your farm' DMD to CP ratio was 4.1 while the strategy ratio increased to 4.3 (data not shown). The net difference in cost of the grain vs the silage was an additional $200/t DM (i.e. silage cost $150/t DM vs grain was $350/t DM, considering wastage of silage fed in the paddock vs grain in the dairy shed). The milk price was set at $0.675/litre, and the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was $35/t CO_2e. In this example, enteric CH_4 emissions increased by 3.5 t CO_2e (shown as a negative value in Figure 74) due to increased intakes associated with additional milk production. However, waste CH_4 declined due to the increased DMD% of the diet offsetting the additional intake due to increased milk production. Waste N_2O emissions declined, as there was less N in the diet, and thus excreted in urine. Net total GHG emissions decreased by 3.5 t CO_2e/annum. Total farm benefit was -$10,229 based on a carbon credit of $123, an additional milk income of $16,649, and an implementation cost of $27,000 (Figure 74). The net change in farm income, relative to the 'Your farm' milk income, was estimated at -0.51%, further illustrating the decline in income with this intervention

due to the high implementation cost (Figure 74). Although not taken into consideration here, the extra milk might require more electricity for milk harvesting and cooling, further reducing net profits as well as increasing GHG emissions from electricity usage. We also didn't consider that if we are feeding less silage over the summer/autumn period, there is the potential for lower fuel consumption on farm, reducing net farm emissions.

This example illustrates the difficulty of improving diet quality (especially digestibility) as this generally increases milk production. The NGGI methodology assumes any increase in milk production occurs because of increased intakes, and given the tight linkage between intake and CH_4, the increased intake results in increased enteric CH_4 production. The price of grain, relative to silage, eroded any profits from additional milk production. Therefore, for this strategy to become profitable, the new supplementary feed needs to be comparative in price to which it is substituting, ideally with a similar DMD% but lower CP%. Alternatively, if DMD% increases but you are confident that intakes, and thus enteric CH_4 has not altered, you could model this scenario as per section 8.1, option c) *Management option to include high-sugar ryegrass pasture in the sward to increase milk production and incorporating a change in diet quality*.

Key variables for the strategy farm	
Enter amount of additional supplement to be fed (kg DM/cow.day)	2.0
Enter digestibility of the additional supplement fed (%)	82.0
Enter crude protein of the additional supplement fed (%)	12.0
Enter estimated substitution rate	1.00
Enter number of days the supplement is fed (days /year)	150
Enter cost of additional supplementary feed ($/t DM)	200
Enter average annual milk price ($/ litre)	$0.675
Enter milk price for when supplements fed ($/litre)	$0.675
Enter on farm price received for a t CO_2e ($)	$35.00
Variation in production	
Estimated change in ME intake (MJ/cow.day)	2.0
Estimated additional milk produced (litres/farm)	24,665
GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	-3.5
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	2.5
Reduction in animal waste N_2O emissions (t CO_2e/annum)	4.5
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	3.5
Reduction in net emissions, relative to your farm system (%)	0.1
Reduction in CH_4 emissions, relative to your farm system (%)	0.0
Reduction in N_2O emissions, relative to your farm system (%)	2.0
Calculated potential carbon credit ($ per farm)	$123
Calculated expense to implement the strategy ($ per farm)	$27,000
Benefit as stand alone abatement ($ per farm)	-$26,877
Estimated additional milk income ($ per farm)	$16,649
Estimated total farm benefit from strategy ($ per farm)	-$10,229
Carbon credit total farm benefit income as % of current milk income	-0.51%

Figure 74. Screenshot of the key variables, variation in production (estimated change in daily diet energy intakes and change in milk production in this example), and GHG and economic results of implementing a strategy of improving the diet's dry matter digestibility to crude protein ratio through supplementation feeding for the milking cow to alter CH_4 and N_2O emissions.

8.9. Coating of N fertiliser with an N inhibitor

This strategy explored the effect of applying N fertilisers coated with a nitrification inhibitor (NI) in terms of reduction in N fertiliser N_2O emissions. Nitrification inhibitors work by retaining fertiliser N in the ammonium (NH_4) form for longer, slowing down the denitrification process where NH_4 converts into nitrate (NO_3), and subsequently into N_2O. Nitrification inhibitors have been found to reduce N losses more consistently, through leaching, on free-draining soils, rather than denitrification losses on waterlogged soils. The NGGI methodology assumes that in addition to a proportion of N being lost as N_2O (direct), a proportion of N fertiliser applied to pastures and crops is also lost through leaching. Subsequently, a small amount of the leached N is also converted in N_2O (indirect). This means any form of retaining N fertiliser in the NH_4 form will generally reduce N losses to the environment.

The effectiveness of NIs is temperature and soil-moisture dependent. Inhibitors are also generally more expensive than commonly used N fertilisers such as urea. Examples of inhibitors include Entec® and N-Protect™. Thus, inhibitor coated fertilisers cost more per unit of N, and are unlikely to result in additional pasture production if there is sufficient soil N to match pasture demand. They can be more cost-effective if the N rate applied is reduced by the expected reduction in N loss. For example, if the timing of the inhibitor could reduce N_2O losses by 10%, reduce the amount of N fertiliser applied by 10%, so the N retained in the NH_4 form can be taken up by the pastures as opposed to converting into NO_3 and N_2O over time.

Key variables for the strategy farm

The Key variables section questions calculates the amount of N fertiliser applied that is coated with the inhibitor, the efficacy of the fertiliser in reducing N_2O losses, the relative difference in cost between the non-coated and coated fertilisers, any potential increase in pasture production, and the utilisation of this pasture, as well as the average annual milk price, and on-farm price received for a tonne of CO_2e (Figure 75). Much of the information needed here will be informed through research projects or from your local agronomist/fertiliser rep who has recommended using a coated product. It is essential that any additional pasture produced with the inhibitor needs to be utilised through grazing and converted into additional milk production for this option to be economically beneficial.

How are the results of the strategy calculated?

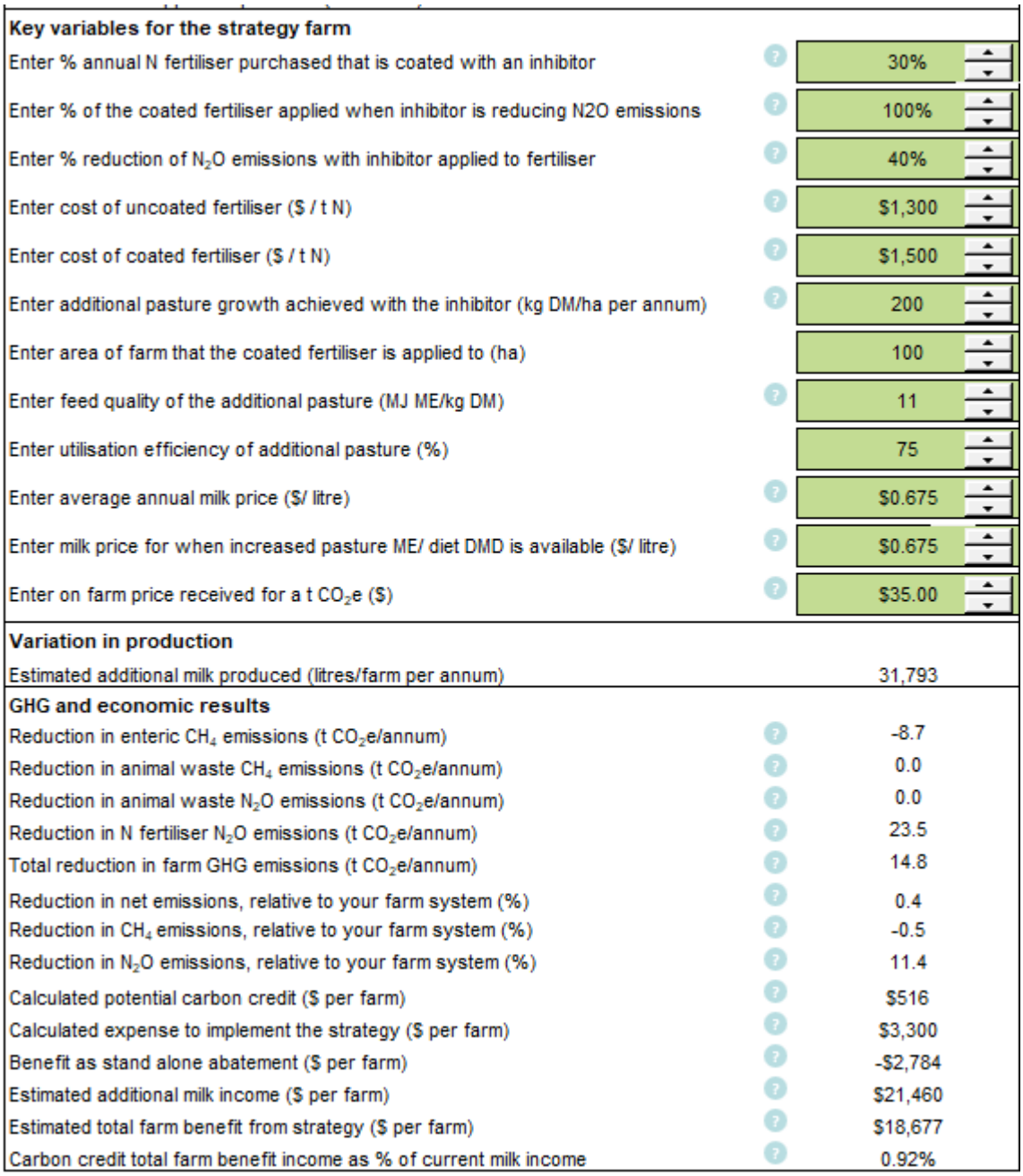
Based on the data entered in the Key variables section, and the 'Your Farm' N fertiliser applied, ADCC calculates the amount of N fertiliser coated with the inhibitor applied during the period of N_2O loss, and the inhibitor's efficacy in reducing N_2O losses. The direct and indirect N_2O losses of the 'Your Farm' are multiplied by the amount of N fertiliser applied with the inhibitor during the period of N loss along with the inhibitor's efficacy, to determine the N_2O loss for the strategy farm. The price differential of the two fertilisers is calculated based on the proportion of fertiliser coated with the inhibitor. Any additional pasture production is multiplied by the energy content of the pasture, the utilisation efficiency of the milking herd to consume the additional pasture, and then divided by 5.5 MJ ME/kg DM, to determine the change in milk production. This will then also alter daily intake and enteric CH_4 emissions. Changes in waste CH_4 and N_2O emissions are not calculated here as the likely increase in pasture consumption will have a minimal impact on these two smaller GHG sources.

Example of results

In the example below (Figure 75), we assumed 30% of the total N fertiliser applied to pastures was coated with the inhibitor, while the inhibitor fertiliser reduced N_2O losses by 40%. The price differential between urea and coated-urea was $200/t N. The inhibitor-coated fertiliser was applied to 100 ha, grew an additional 0.2 t DM/ha.annum at an energy concentration of 11 MJ/kg DM (~ 75% DMD), overall diet CP% did not alter, and 75% of the additional pasture grown was consumed, and converted into milk (extra ~ 31,800 litres per annum). The milk price was set at $0.675/litre, and the on-farm price for a reduction in CO_2e emission (after additional administrative costs) was $35/t CO_2e.

In this example, enteric CH_4 emissions increased by 8.7 t CO_2e/annum due to the inhibitor resulting in more pasture being grown and consumed. Nitrogen fertiliser N_2O emissions declined because of the inhibitor, and by an amount greater than the increase in enteric CH_4 emissions. Thus, total emissions declined by 14.8 t CO_2e/annum. Total farm benefit was $18,677, based on a carbon credit of $516, an additional milk income of $21,460, and an implementation cost of $3,300 (Figure 75). The net change in farm income, relative to the 'Your farm' milk income, was estimated at 0.92% (Figure 75). Although not taken into consideration here, the extra milk might require more electricity for milk harvesting and cooling, further reducing net profits as well as increasing GHG emissions from electricity usage.

If there was no additional pasture produced because the soil was already saturated with N, and thus the 'saved N was not needed by the pastures, enteric CH_4 emissions would not alter compared to the 'Your Farm'. Thus, only the reduction in N_2O losses would generate a carbon income, in this example 23.5 t CO_2e saved x $35/ t CO_2e = ~ $820/annum carbon income. However, the cost of the inhibitor might be greater than the carbon credit, resulting in an unprofitable abatement option. This example illustrates the need to understand, and follow all sources of GHG emissions, not just those targeted with the strategy. This also highlights the need to reduce the rate of N-inhibitor fertiliser applied by the rate of savings in N_2O predicted, so the N retained in the soil can be taken up by pastures. For example, if you normally apply 40 kg N/ha during late winter/early spring, and the inhibitor is estimated to save 20% of N losses, reduce the rate of N-inhibitor fertiliser by 20% to 32 kg N/ha. Additionally, this would also reduce the Scope 3 embedded emissions associated with the production of N fertiliser no longer required. This could be explored as an option with the 'Strategy Farm' tab in terms of generating an income through reduced emissions which would then need to be incorporated into this strategy.



Key variables for the strategy farm		
Enter % annual N fertiliser purchased that is coated with an inhibitor		30%
Enter % of the coated fertiliser applied when inhibitor is reducing N2O emissions		100%
Enter % reduction of N_2O emissions with inhibitor applied to fertiliser		40%
Enter cost of uncoated fertiliser ($ / t N)		$1,300
Enter cost of coated fertiliser ($ / t N)		$1,500
Enter additional pasture growth achieved with the inhibitor (kg DM/ha per annum)		200
Enter area of farm that the coated fertiliser is applied to (ha)		100
Enter feed quality of the additional pasture (MJ ME/kg DM)		11
Enter utilisation efficiency of additional pasture (%)		75
Enter average annual milk price ($/ litre)		$0.675
Enter milk price for when increased pasture ME/ diet DMD is available ($/ litre)		$0.675
Enter on farm price received for a t CO_2e ($)		$35.00
Variation in production		
Estimated additional milk produced (litres/farm per annum)		31,793
GHG and economic results		
Reduction in enteric CH_4 emissions (t CO_2e/annum)		-8.7
Reduction in animal waste CH_4 emissions (t CO_2e/annum)		0.0
Reduction in animal waste N_2O emissions (t CO_2e/annum)		0.0
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)		23.5
Total reduction in farm GHG emissions (t CO_2e/annum)		14.8
Reduction in net emissions, relative to your farm system (%)		0.4
Reduction in CH_4 emissions, relative to your farm system (%)		-0.5
Reduction in N_2O emissions, relative to your farm system (%)		11.4
Calculated potential carbon credit ($ per farm)		$516
Calculated expense to implement the strategy ($ per farm)		$3,300
Benefit as stand alone abatement ($ per farm)		-$2,784
Estimated additional milk income ($ per farm)		$21,460
Estimated total farm benefit from strategy ($ per farm)		$18,677
Carbon credit total farm benefit income as % of current milk income		0.92%

Figure 75. Screenshot of the key variables, variation in production (estimated change in milk production in this example), and GHG and economic results of implementing a strategy of applying N fertiliser coated with a nitrification inhibitor to reduce N_2O losses, alter milk production, and enteric CH_4 emissions.

8.10. Applying N inhibitors to urine patches

This strategy explored the hypothetical concept of applying a nitrification inhibitor (NI) to the animal through their feed, so that as they urinate in the paddock, the urine patches will already contain the NI. This contrasts with applying a NI, in a spray form, across the whole paddock post-grazing. Urine patches are generally extremely high in N content, up to 1,000kg N/ha (de Klein and Eckard, 2008). These are much greater concentrations than growing pastures have the capacity to take up. This strategy explored the question of how much could we reduce N_2O loss if we could dose the animal with the NI, thus retaining urinary N in the ammonium (NH_4) form for longer, slowing down the denitrification process where NH_4 converts into nitrate (NO_3), and subsequently into N_2O. This contrasts with applying an inhibitor to N-based fertilisers (see section 8.9), along the desired outcome is the same; reducing the rapidity of NH_4 converting to N_2O. It is unlikely that dosing animals with NIs would result in any additional milk production. But for consistency with the other strategies, we have included an 'Estimated additional milk production' result in the Variation in production section to reinforce no change in milk production.

Nitrification inhibitors have been found to reduce N losses more consistently, through leaching, on free-draining soils, rather than denitrification losses on waterlogged soils. The NGGI methodology assumes that in addition to a proportion of N being lost as N_2O (direct), a proportion of N fertiliser applied to pastures and crops is also lost through leaching. Subsequently, a small amount of the leached N is also converted in N_2O (indirect). This means any form of retaining N fertiliser in the NH_4 form will reduce losses to the environment.

The effectiveness of NIs is temperature and soil-moisture dependent. It is likely that farmers would only need to dose their animals at times of the year when the risk of leached N and N_2O losses are greatest. This is likely late autumn through early spring in southern Australia, although potentially year-round in northern Australia due to the sporadic nature of large rainfall events (e.g. summer cyclonic storms).

Key variables for the strategy farm

The Key variables section questions determine the proportion of total urinary N that is deposited onto paddocks while grazing, the number of days per annum the inhibitor is effective, the efficacy of the inhibitor, the cost of implementation, as well as the average annual milk price, and on-farm price received for a tonne of CO_2e (Figure 76). Much of the information needed here will be informed through research projects or from your local agronomist or supplier of the inhibitor.

How are the results of the strategy calculated?

The strategy farm's direct and indirect N_2O emissions from leached N is reduced by the proportion of urinary N deposited onto pastures over the number of days per year the inhibitor is effective, and by the efficacy rate. Unlike most other strategies, we have assumed this strategy is unlikely to result in any change in milk production.

Example of results

In the example below (Figure 76), we assumed the cows spent 85% of their time grazing pasture (balance at the dairy, on a feedpad etc). The nitrification inhibitor effectively reduced N_2O losses for 180 days per annum, reducing N_2O losses by 30%. The cost of implementation was $6/cow per annum, and any reduction in net GHG emissions was valued at $35/t CO_2e (Figure 76). Total farm benefit was -$1,217, based on a carbon credit of $1,483, and an implementation cost of $2,700. The net change in farm income, relative to the 'Your farm' milk income, was estimated at -0.06% due to the higher cost to implement relative to any income derived from reducing GHG emissions (Figure 76). By using the scroll up/down arrows, with the same above-mentioned assumptions, we could quickly determine that a carbon price of ~ $64/t CO_2e would be needed for this strategy to become cost neutral if the cost to implement was $6/cow per annum. Conversely, an implementation cost of ~ $3.30/cow per annum would be required to make this abatement option financially viable, based on a carbon price of $35/t CO_2e.

Key variables for the strategy farm	
Enter time cows spend grazing on pastures (% of year)	85
Enter number of days per year the inhibitor is effective (days/year)	315
Enter efficacy of nitrification inhibitor (%)	30
Enter cost to implement strategy ($ per cow per annum)	$6.00
Enter average annual milk price ($/ litre)	$0.675
Enter on farm price received for a t CO_2e ($)	$35.00
Variation in production	
Estimated additional milk produced (litres/farm)	0
GHG and economic results	
Reduction in enteric CH_4 emissions (t CO_2e/annum)	0.0
Reduction in animal waste CH_4 emissions (t CO_2e/annum)	0.0
Reduction in animal waste N_2O emissions (t CO_2e/annum)	42.4
Reduction in N fertiliser N_2O emissions (t CO_2e/annum)	0.0
Total reduction in farm GHG emissions (t CO_2e/annum)	42.4
Reduction in net emissions, relative to your farm system (%)	1.2
Reduction in CH_4 emissions, relative to your farm system (%)	0.0
Reduction in N_2O emissions, relative to your farm system (%)	19.1
Calculated potential carbon credit ($ per farm)	$1,483
Calculated expense to implement the strategy ($ per farm)	$2,700
Benefit as stand alone abatement ($ per farm)	-$1,217
Estimated additional milk income ($ per farm)	$0
Estimated total farm benefit from strategy ($ per farm)	-$1,217
Carbon credit total farm benefit income as % of current milk income	-0.06%

Figure 76. Screenshot of the key variables, variation in production (estimated change in milk production in this example), and GHG and economic results of implementing a strategy of dosing the milking herd with a nitrification inhibitor so their urine patches are already inhibited, thus reducing N_2O losses.

8.11. Whole-farm abatement strategy

Sections 8.1 to 8.10 explored abatement strategies that targeted a specific part of the farm system to alter CH_4 and/or N_2O emissions. The whole-farm abatement strategy differs from all others, in that users can alter one or more aspects of the 'Your Farm' system, to ascertain the effect on the whole farm system. Examples could include:

- Produce the same amount of milk from fewer cows,
- Reducing N fertiliser inputs but achieving the same amount and quality of pasture,
- Increasing milk production per cow through genetic improvement,
- Replacing grid-sourced electricity with renewables generated on farm,
- Planting trees on farm,
- Compare the default state-based factors for manure management with on-farm practices,
- Retain non-replacement calves and fattening them for the beef market

Key variables for the strategy farm

The 'Strategy Farm' tab is automatically populated with the data you enter on the 'Your Farm' tab. All entry cells will be green and unprotected. Each green cell has an equation linking back to the 'Your Farm' tab. For example, the milking herd size cell has ='Your Farm'!D18 indicating the number here is the same as that found in cell D18 of the 'Your Farm' tab. This equation will be lost if users enter new data over any of the green entry cells.

NOTE the one exception to this is with tree plantings sequestration. While area of land under trees and the average age of the trees is linked to the 'Your Farm' tab, the three questions on the left-hand side of this section will start off as being linked, but as soon as you change one of more drop-down list entries, the link is removed and thus you need to manually use the drop-down list to revert the entry data back to that of the 'Your Farm' system. The most common example would be that the 'Your Farm' system had Tasmanian Blue Gums and the user wants to explore the option of replacing these with Environmental plantings. Users may wish to explore the implications of having the exact same farm and trees but in another region of their state, or the value of buying additional land in a different region of Australia to purposely plant trees. Therefore, be mindful of this section, and to help with this, the colouring of the cells will alter to indicate when the 'Your farm' and 'Strategy farm' data entry matches (green cell/ black text) or alters (red cell/white text).

We suggest the best way to manage this tab is to alter the equation so you can revert to the original 'Your farm' numbers as required. For example, if we wanted to milk 50 more cows than the 'Your Farm', change the Strategy farm equation in D19 to ='Your Farm'!D19+50. Conversely, if you wanted to milk 50 less cows than the 'Your Farm', change the Strategy farm equation in D18 to ='Your Farm'!D19-50. When the cell answer is altered, relative to the 'Your Farm' system, the cell changes colour from green to red, while the text alters from black to white. This allows users to quickly identify which aspects of the tab have been altered (Figure 77). If a change is no longer required, the user can just delete the additional component of the sum. For example, by removing +50 or -50 in the two examples above, the cell equation will revert to the 'Your farm' value, and the format will revert back to a green cell with black text.

If you accidentally remove the equation in a green cell, the cell will become red, indicating a change away from the 'Your farm' value. You will need to reinstate the linkage back to the 'Your Farm' tab, otherwise estimates of GHG emissions will not be correct. If possible, click on the Undo button, found on the Home tab within Excel until the equation is reinstated. This may take a few clicks of the Undo button, depending on how many changes were made after the accidental removal. A second option would be to reinstate the equation back into the deleted cell. Th easiest way to do this is on the 'Strategy Farm' tab, located the cell which has been deleted, type in an equals (=) sign, then go back to the matching cell on the 'Your Farm' tab cell and click in that cell. This should reinstate the equation,

repopulating the same number for the Strategy farm as per the 'Your Farm'. As a last alternative, you could download another copy of ADCC from the Dairy Australia website and copy the deleted equation from the 'Strategy Farm' tab of the newly downloaded file and paste back into your working copy of ADCC.

In the example below (Figure 77), the milking cows and heifers < 1 year of age have been altered but the heifers > 1 year of age have not. The user then needs to also determine what other aspects of the farm system need altering. For example, if you are milking fewer cows, how does milk production change, does your electricity consumption come down, do you need to purchase the same amount of supplementary feed etc? The calculator **cannot** estimate these changes.

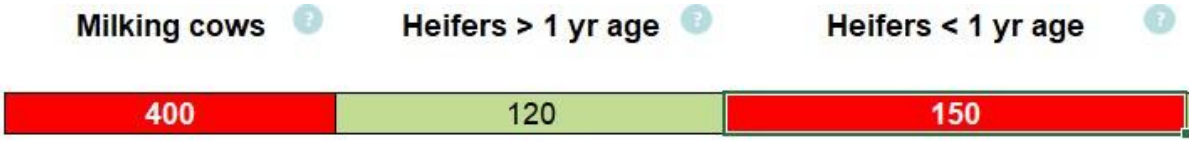


Figure 77. Illustration of changing the whole-farm abatement strategy milking cow and heifers < 1 yr age numbers, with the cell altering from black text in a green cell to white text in a red cell. Heifers > 1 yr of age have remained the same as the 'Your Farm' system.

How are the results of the strategy calculated?

The whole-farm abatement strategy calculations remain the same as the 'Your Farm' system, using the altered inputs to determine changes in GHG emissions. We are comparing two steady-state farms, not the transition from one to the other. For example, a 'Your Farm' with 10 ha of 15 year old trees vs a strategy farm with 15 ha of 15 year old trees. As the user can alter one or more aspects of the farm, a new results table is shown along with a bar chart for each source of emissions, illustrating the change in EI, relative to the 'Your Farm' system. Changes to the farm system may incur economic implications, costing more to implement or saving on costs that otherwise would be incurred.

Example of results

In the example below (Figure 78, individual changes not shown due to the scope of changes made), we assumed the farm milked 50 fewer cows per annum. However, we also assumed that there was no change in annum milk production as the cows remaining had access to more pasture, resulting in an improvement in milk production for the remaining cows. The number of replacements also declined by 10 heifers per age group, relative to the 'Your Farm' system. The number of bull calves retained, and taken onto fattening, remained the same. Thus, there was 40 fewer calves being sold post-weaning. The amount of purchased grain was reduced by 15 tonnes of DM/annum. In addition, having fewer animals on farm meant that the amount of land under trees could be increased to 15 ha. All other aspects remained the same (i.e. no change to electricity and fuel consumption or altered fertiliser inputs). The reduction in grain feeding, lower animal herd costs (i.e. lower AI costs, herd health costs etc), coupled with raising fewer heifers. However, the reduction in calves sold post-weaning would erode much of these savings. In addition, we would need to put a cost associated with planting another 5 ha of trees. Therefore it is critical to understand and estimate all economic aspects which may alter because of changes in the overall farm system.

In this example, animal-related CH_4 and N_2O emissions, and pre-farm embedded emissions all declined, while carbon sequestration increased. Net farm GHG emissions declined by ~ 167 t CO_2e/annum (data not shown here). As milk production remained the same, there were small reductions in milk and meat EI (data not shown). The reduction in net GHG emissions, at \$35/t CO_2e, generated a carbon credit income of \$5,851. When coupled with the savings of \$6,500, total farm benefits increased by \$12,351/annum (Figure 78). Note that it is highly unlikely that changes like this for a farm system, apart from planting additional land to trees, would qualify for carbon credits. Thus, the real benefit was the reduction in expenses with milking fewer cows and having less replacement animals.

Economic implications of changing your farm system	
Enter the cost to implement the change on farm ($ per annum)	$0
Enter any savings that may occur due to implementing the change on farm ($ per annum)	$6,500
Enter the milk price when the changes are implemented ($/litre milk)	$0.675
Enter on farm price received for a t CO2e ($)	$35.00
Calculated potential carbon credit ($ per farm)	$5,851
Calculated net expense to implement the strategy ($ per farm)	-$6,500
Benefit as stand alone abatement ($ per farm)	$12,351
Estimated additional milk income ($ per farm)	$0
Estimated total farm benefit from strategy ($ per farm)	$12,351

Figure 78. Screenshot of the key variables and changes in economic results when changing a range of aspects of the 'Strategy Farm' tab, including milking fewer cows, thus retaining fewer replacement animals, and increasing the area of the farm with trees present to sequester carbon (note columns in excel have been altered to better view the results presented here).

9. Resources

General resources not listed below in abatement/mitigation option reviews

Similar to below in the *Abatement options review* section, this list is not exhaustive but an indication of where you might be able to gain additional information and resources around dairy greenhouse gas emissions and potential abatement strategies.

Agriculture Victoria (2022) Soil Carbon Snapshot https://agriculture.vic.gov.au/__data/assets/pdf_file/0006/857607/Soil-Carbon-Snapshot-updated-May-2022.pdf

Dairy Australia's Climate and Environment website https://www.dairyaustralia.com.au/climate-and-environment

Dairy Australia's Energy Savings tips website https://www.dairyaustralia.com.au/climate-and-environment/greenhouse-gas-emissions/energy-saving-tips

Dairy Australia's Fertiliser Management website https://www.dairyaustralia.com.au/soils-and-water/soil-management-and-fertility/fertiliser-management

Dairy Australia's Greenhouse Gas Emissions website https://www.dairyaustralia.com.au/climate-and-environment/greenhouse-gas-emissions

Dairy Australia's Soils and Water website https://www.dairyaustralia.com.au/soils-and-water

Fert$mart Nitrogen Pocket Guide https://www.dairyaustralia.com.au/soils-and-water/soil-management-and-fertility/nitrogen-fertilisers/resources

Moss, A. (2020) Database of nutrient content of Australian feed ingredients https://agrifutures.com.au/wp-content/uploads/2020/09/20-078.pdf

Some aspects, such as reproductive management, are also important to consider when implementing on-farm practices to reduce farm GHG emissions, so think 'outside the box' for areas to consider when reviewing resources available. There are also a lot of resources in the Profitable Emissions Action Plan.

Abatement option reviews

There are many reviews of abatement options for ruminant livestock, therefore the listing below is not exhaustive.

Beauchemin KA, Ungerfeld EM, Eckard RJ, Wang M (2020) Review: Fifty years of research on rumen methanogenesis: lessons learned and future challenges for mitigation. *Animal* **14:S1**, s2-s16. https://www.cambridge.org/core/journals/animal/article/review-fifty-years-of-research-on-rumen-methanogenesis-lessons-learned-and-future-challenges-for-mitigation/8F7537B81CBDA633F48663C1ACF33036

Black JL, Davison TM, Box I (2021) Methane emissions from ruminants in Australia: Mitigation potential and applicability of mitigation strategies. *Animals* **11**, 951. https://www.mdpi.com/2076-2615/11/4/951

Eckard RJ, Clarke H (2018) Potential solutions to the major greenhouse-gas issues facing Australasian dairy farming. *Animal Production Science* **60**, 10-15. https://www.publish.csiro.au/AN/AN18574

Eckard RJ, Grainger C, de Klein CAM (2010) Options for the abatement of methane and nitrous oxide from ruminant production – a review. *Livestock Science* **130**, 47-56. https://www.sciencedirect.com/science/article/pii/S1871141310000739

Garnett LM, Eckard RJ (2024) Greenhouse-gas abatement on Australian dairy farms: what are the options? *Animal Production Science* **64**, AN24139. https://www.doi.org/10.1071/AN24139

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G (2013) Tackling climate change through livestock- A global assessment of emissions and mitigation opportunities.

(Food and Agriculture Organization of the United Nations (FAO): Rome, Italy). https://www.fao.org/3/a0701e/a0701e.pdf

Harrison MT, Cullen BR, Mayberry DE, Cowie AL, Bilotto F, Badgery WB, Liu K, Davison T, Christie KM, Muleke A, Eckard RJ (2021) Carbon myopia: The urgent need for integrated social, economic and environmental action in the livestock sector. *Global Change Biology* **27**, 5726-5761. https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.15816

Hodge I, Quille P, O'Connell S (2024) A review of potential feed additives intended for carbon footprint reduction through methane abatement in dairy cattle. *Animals* **14**, 568, https://doi.org/10.3390/ani14040568

Hristov AN, Oh J, Lee C, Meinen R, Montes F, Ott T, Firkins J, Rotz A, Dell C, Adesogan A, Yang W, Tricarico J, Kebreab E, Waghorn G, Dijkstra J, Oosting S (2013) Mitigation of greenhouse gas emissions in livestock production- A review of technical options for non-CO_2 emissions. https://www.fao.org/publications/card/en/c/87178c51-d4d1-515d-9d0e-b5a6937fa631/

Hristov AN, Oh J, Firkins JL, Dijkstra J, Kebreab E, Waghorn G, Makkar HPS, Adesogan AT, Yang W, Lee C, Gerber PJ, Henderson B, Tricarico JM (2013) SPECIAL TOPICS- Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane operations. *Journal of Animal Science* **91**, 5045-5069. https://academic.oup.com/jas/article/91/11/5045/4731308

Hristov AN, Ott T, Tricarico JM, Rotz A, Waghorn G, Adesogan A, Dijkstra J, Montes F, Oh J, Kebreab E, Oosting SJ, Gerber PJ, Henderson B, Makkar HPS, Firkins JL (2013) SPECIAL TOPICS- Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. *Journal of Animal Science* **91**, 5095-5113. https://academic.oup.com/jas/article/91/11/5095/4731330

Llonch P, Haskell MJ, Dewhurst RJ, Turner SP (2017) Review: current available strategies to mitigate greenhouse gas emission in livestock systems: an animal welfare perspective. *Animal* **11**, 272-284. https://www.cambridge.org/core/services/aop-cambridge-core/content/view/2C1E6F2AA8B6608B9B5C49544EEB26F4/S1751731116001440a.pdf/current-available-strategies-to-mitigate-greenhouse-gas-emissions-in-livestock-systems-an-animal-welfare-perspective.pdf

Min BR, Solaiman S, Waldrip HM, Parker D, Todd RW, Brauer D (2020) Dietary mitigation of enteric methane emissions from ruminants: A review of plant tannin mitigation options. *Animal Nutrition* **6**, 231-246. https://reader.elsevier.com/reader/sd/pii/S2405654520300706?token=4113F5241001D734B17EB067E8A665DA98A9B4DB00CF0D2264E4708B879AEFB550EC7EDC61A4FB66DF7A5B40D61D2A2E&originRegion=us-east-1&originCreation=20220318052754

Montes F, Meinen R, Dell C, Rotz A, Hristov AN, Oh J, Waghorn G, Gerber PJ, Henderson B, Makkar HPS, Dijkstra J (2013) SPECIAL TOPICS – Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. *Journal of Animal Science* **91**, 5070-5094. https://academic.oup.com/jas/article/91/11/5070/4731316

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Australian Government (2025) National Inventory Report 2023: The Australian Government Submission to the United Nations Framework Convention on Climate Change. Available at https://www.dcceew.gov.au/climate-change/publications/national-inventory-report-2023

Charmley E, Williams SRO, Moate PJ, Hegarty RS, Herd RM, Oddy VH, Reyenga P, Staunton KM, Anderson A, Hannah MC (2016) A Universal equation for predicting methane production of forage-fed cattle in Australia. *Animal Production Science* **56**, 169-180.

Christie KM, Gourley CJP, Rawnsley RP, Eckard RJ, Awty IM (2012) Whole-farm systems analysis of Australian dairy farm greenhouse gas emissions. *Animal Production Science* **52**, 998-1011.

Christie KM, Rawnsley RP, Phelps C, Eckard RJ (2018) Revised greenhouse-gas emissions from Australian dairy farms following application of updated methodology. *Animal Production Science* **58**, 937-942.

Christie KM, Rawnsley RP, Harrison MT, Echard RJ (2014) Using a modelling approach to evaluate two options for improving animal nitrogen use efficiency and reducing nitrous oxide emissions on dairy farms in southern Australia. *Animal Production Science* **54**, 1960-1970.

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Dairy Australia (2021) Australian Dairy Industry Sustainability Report 2020. Available at https://www.dairy.com.au/sustainability/australian-dairy-sustainability-framework

de Klein CAM, Eckard RJ (2008) Targeted technologies for nitrous oxide abatement from animal agriculture. *Australian Journal of Experimental Agriculture* **48**, 14-20.

Eckard RJ, Grainger C, de Klein CAM (2010) Options for the abatement of methane and nitrous oxide from ruminant production – a review. *Livestock Science* **130**, 47-56.

Flysjö A, Cederberg C, Henriksson M, Ledgard S (2011) How does co-product handling affect the carbon footprint of milk? Case study of milk production in New Zealand and Sweden. *International Journal of Life Cycle Assessment* **16**, 420-430.

IDF (2022) The IDF global Carbon Footprint standard for the dairy section. Bulletin of the IDF No. 520/2022. (International Dairy Federation: Brussels, Belgium). Available at https://fil-idf.org/

IPCC (2014). IPCC Fifth Assessment Synthesis Report-Climate Change 2014 Synthesis Report. In *IPCC Fifth Assessment Synthesis Report-Climate Change 2014 Synthesis Report*. Available at https://www.ipcc.ch/assessment-report/ar5/

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Min BR, Solaiman S, Waldrip HM, Parker D, Todd RW, Brauer D (2020) Dietary mitigation of enteric methane emissions from ruminants: A review of plant tannin mitigation options. *Animal Nutrition* **6**, 231-246.

Moate PJ, Deighton MH, Williams SRO, Pryce JE, Hayes BJ, Jacobs JL, Eckard RJ, Hannah MC, Wales WJ (2016) Reducing the carbon footprint of Australian milk production by mitigation of enteric methane emissions. *Animal Production Science* **56**, 1017-1034.

Moate PJ, Williams SRO, Grainger C, Hannah MC, Ponnampalam EN (2011) Influence of cold-pressed canola, brewers grains and hominy meal as dietary supplements suitable for reducing enteric methane emissions from lactating dairy cows. *Animal Feed Science and Technology* **166-167**, 254-264.

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Simon PL, de Klein CAM, Worth W, Rutherford AJ, Dieckow J (2019) The efficacy of Plantago lanceolata for mitigating nitrous oxide emissions from cattle urine patches. *The Science of the Total Environment* **691**, 430-441.

Smith AP, Christie KM, Harrison MT, Eckard RJ (2021) Ammonia volatilisation from grazed, pasture based dairy farming systems. *Agricultural Systems* **190**, 103119.

Thoma G, Nemecek T (2020) Allocation between milk and meat in dairy LCA: critical discussion of the IDF's standard methodology. In 'Proceedings of the 12th International Conference on Life Cycle Assessment of Food', LCA Food 2020, pp 83-89, Berlin, Germany.

Turner LR, Donaghy DJ, Pembleton KG, Rawnsley RP (2015) Longer defoliation interval ensures expression of the 'high sugar' trait in perennial ryegrass cultivars in cool temperate Tasmania, Australia. *Journal of Agricultural Science* **153**, 995-1005.

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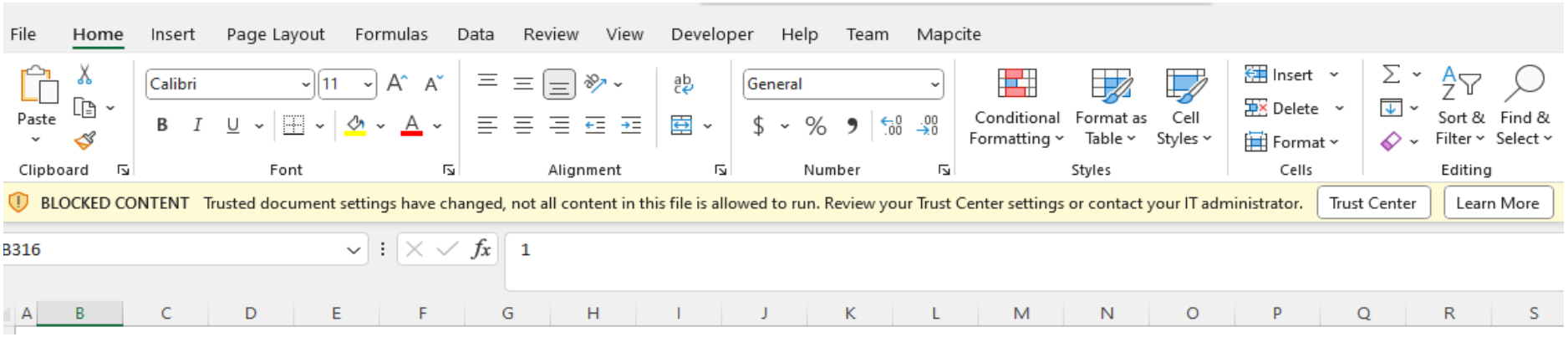
11. Appendices

Appendix 1 Enabling macros instructions

When opening ADCC version 6.1 for the first time, you will need to enable macros. This is a new addition to the calculator and has been incorporated to allow users of DairyBase to import farm system files into ADCC. Once you have enabled macros for the file, you should no longer need to repeat this process.

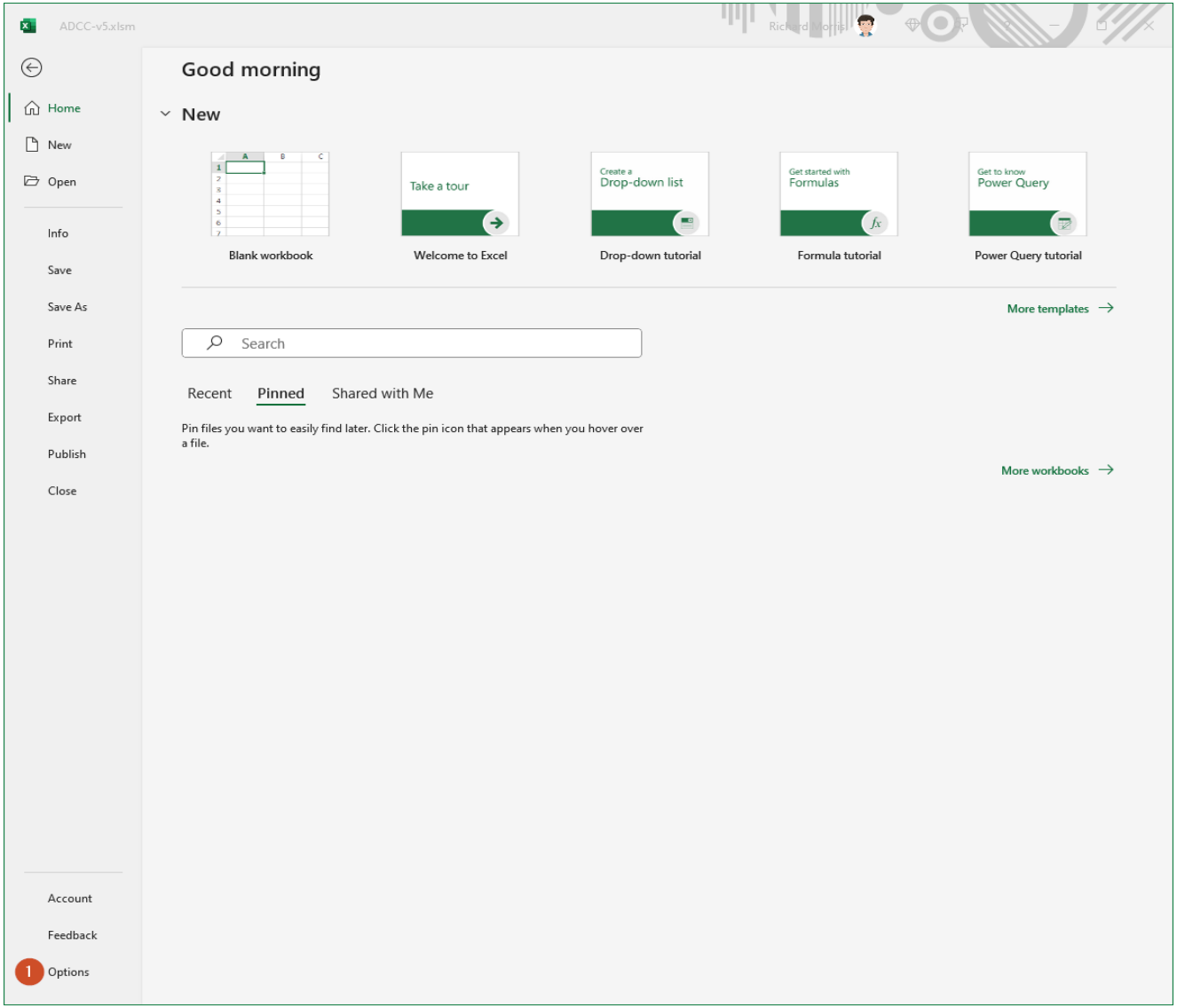
To run the macro, the Excel macros security settings must be set correctly. If they are too high, you will get an error message like the one below when you open the spreadsheet. The first set of instructions are for Windows PCs; the second set are for Apple Macs.

Excel for Windows instructions

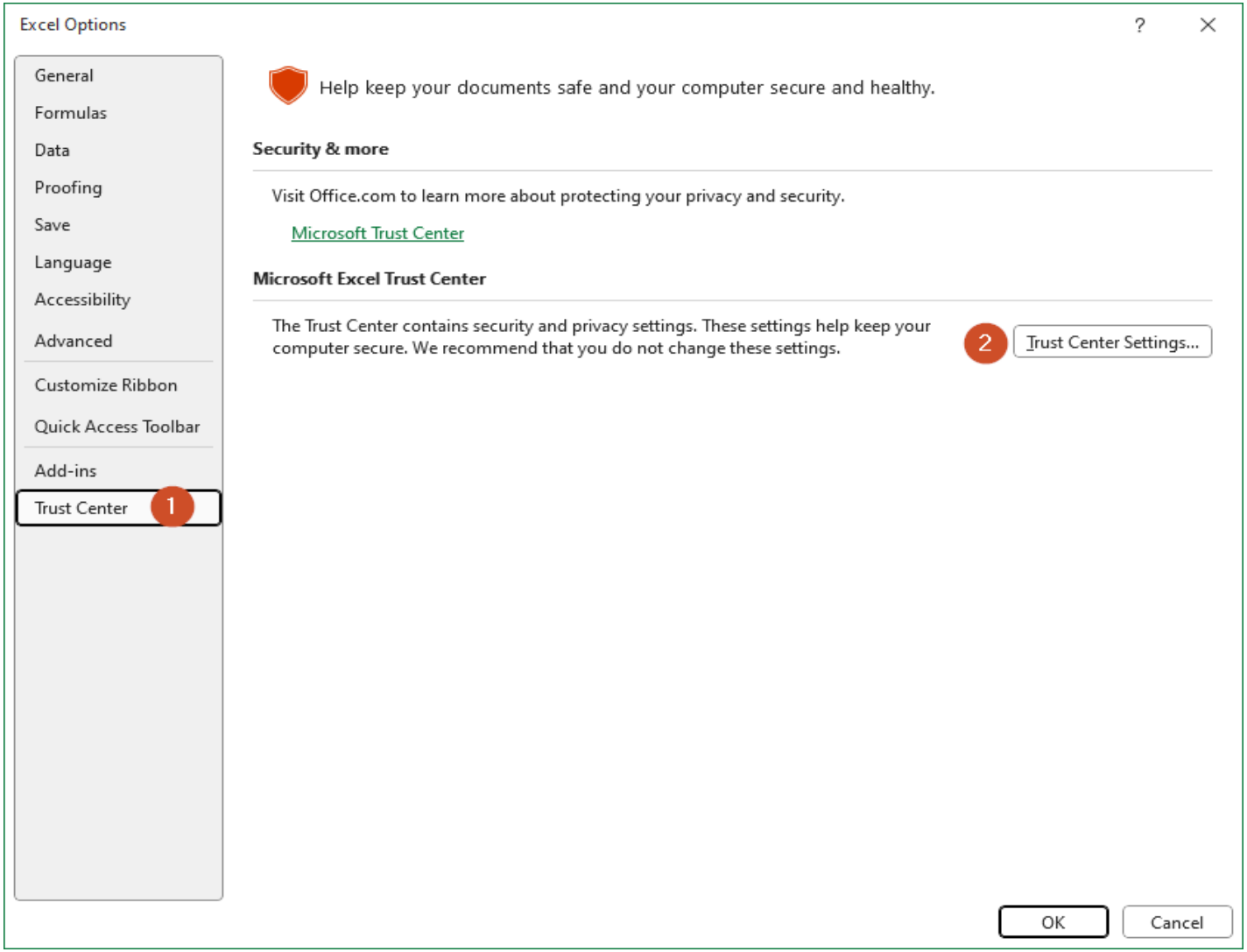


1. If you get the message above, click on the 'Trust Center' button to go straight to the macros security settings options (skip to step 3 below). If you get a red warning similar to the one below, continue onto step 2.

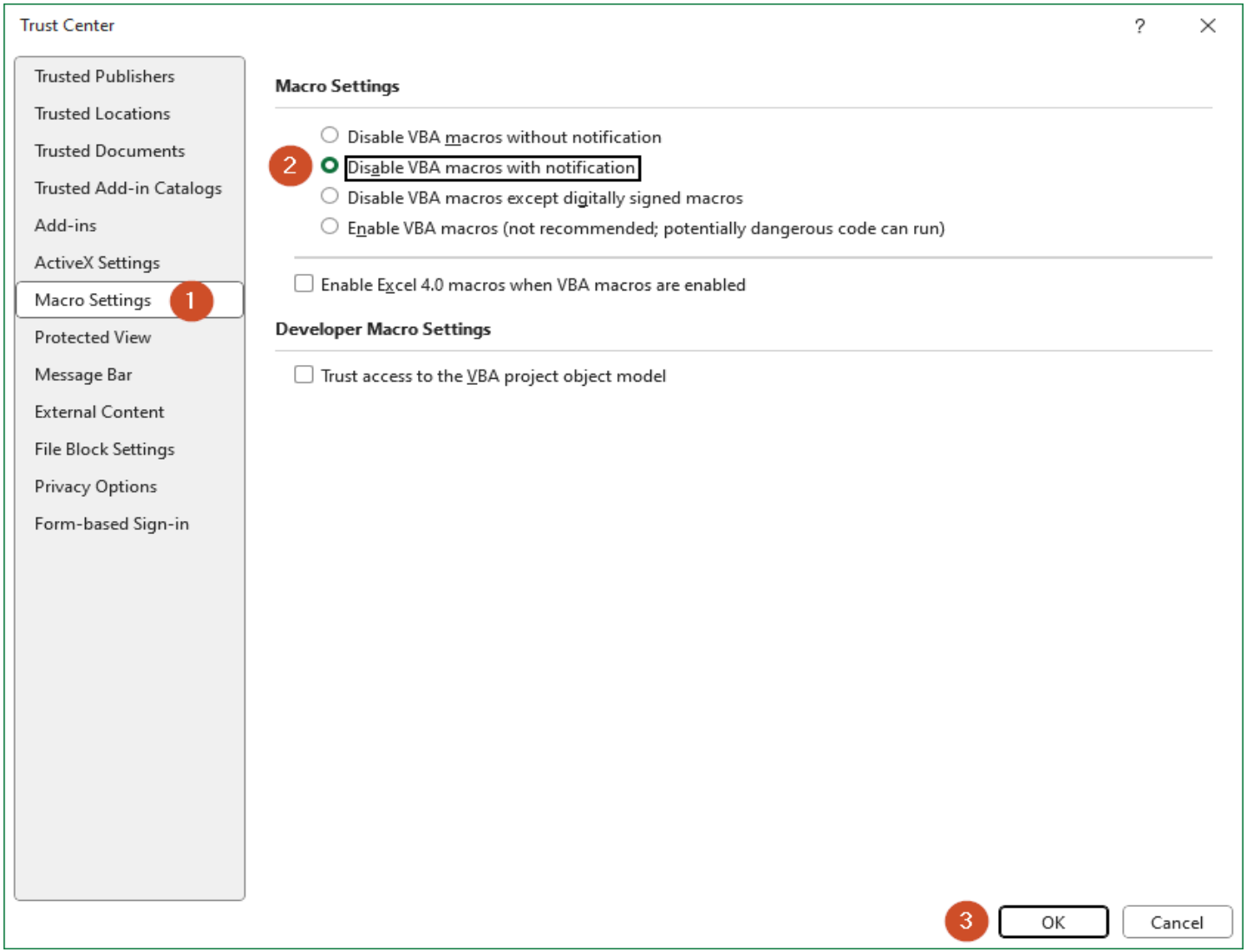
2. Click on the ‘File’ menu at the top left of the Excel window, then click on the ‘Options’ button at the bottom left.



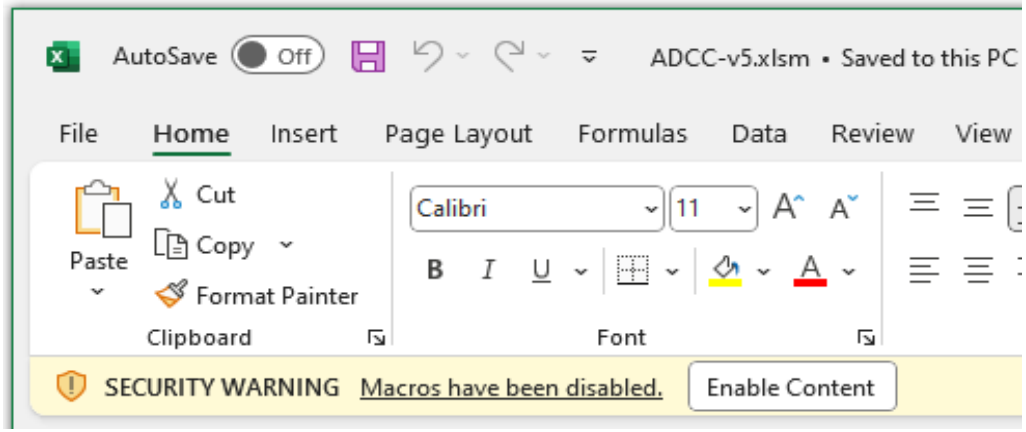
3. Within the Options window, click on the ‘Trust Center’ option from the left hand side menu (1) and then the ‘Trust Center Settings’ button on the right hand side.



4. Within the Trust Center, select the ‘Macro Settings’ in the left hand side (1), then change the Macro settings to the second level down (2) ‘Disable VBA macros with notification’. You can then click on the ‘OK’ button (3) two times to return to the spreadsheet window.

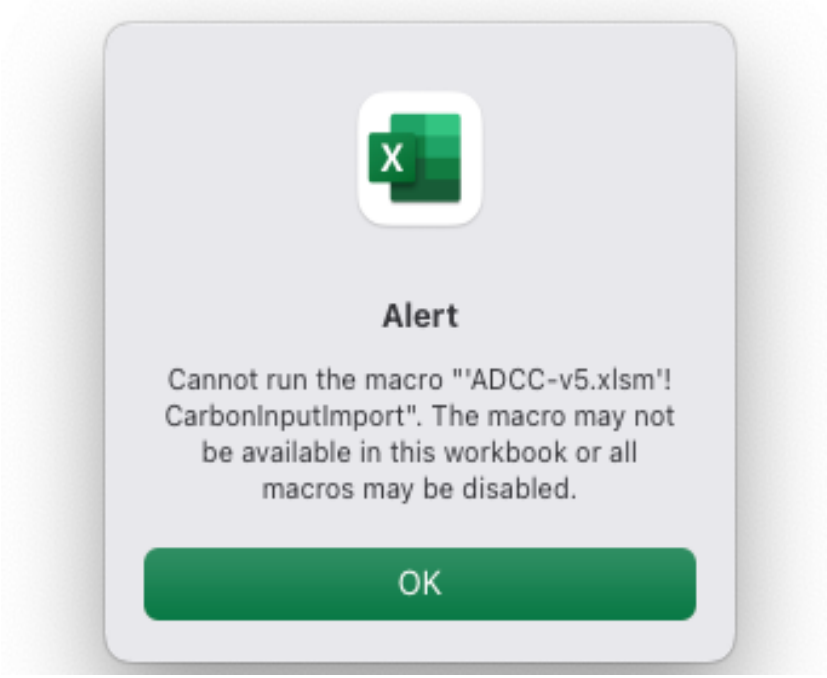


5. Now when a spreadsheet containing a macro opens for the first time, you will be prompted at the top of the window that macros have been disabled, but you need to enable the macros if the spreadsheet is from a trusted source (e.g. Dairy Australia), by clicking on the 'Enable Content' button as shown below. **Warning: Never enable macros in a spreadsheet unless you are sure it can be trusted! Macros in Office documents and files are a common source of malicious content.**

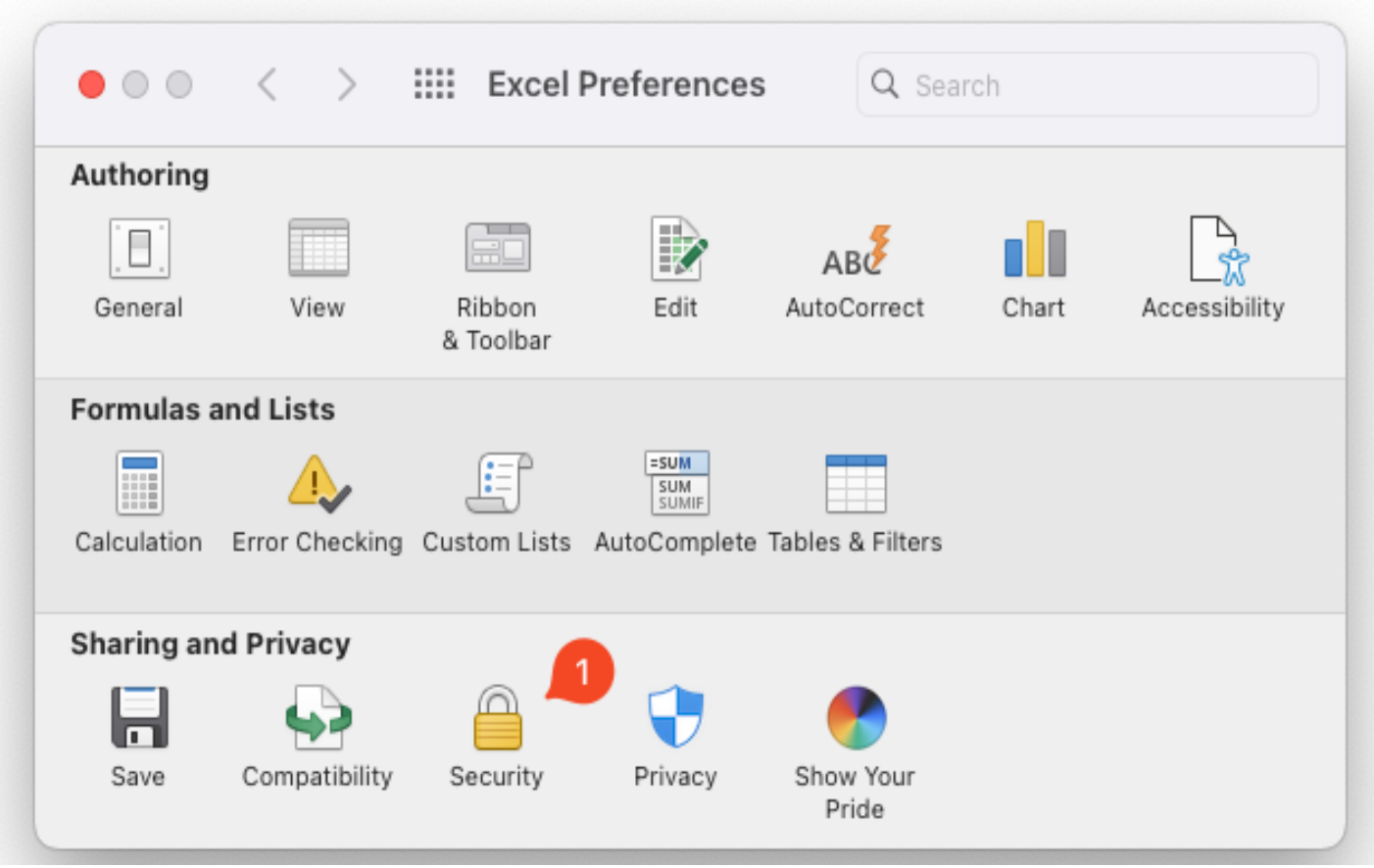


Excel for Mac instructions

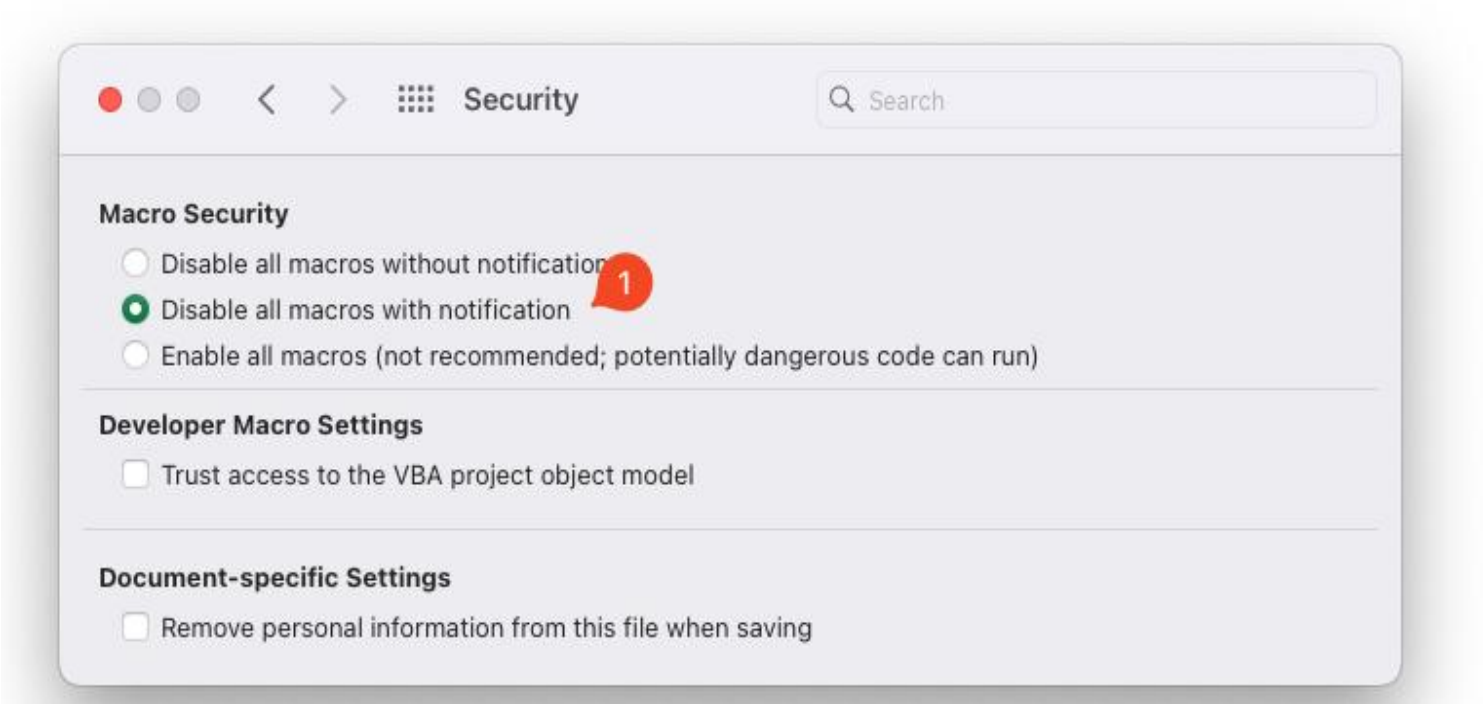
To run the macro, the Excel macros security settings must be set correctly. If they are too high, you will get an error message like the one below when you open the spreadsheet.



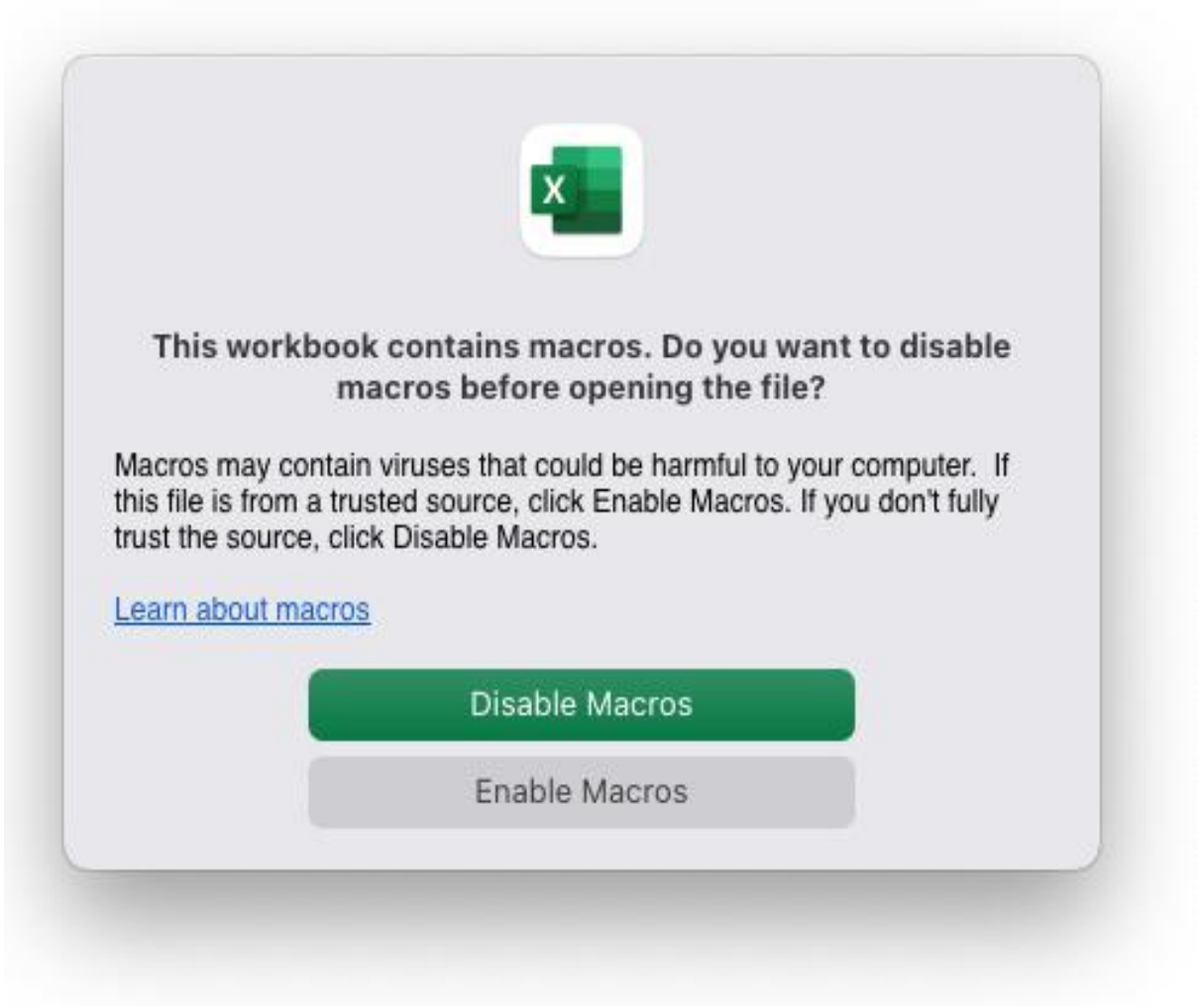
1. Go to the Excel menu and the top right of the screen and click on the Preference sub-menu.



2. Click on the ‘Security’ preferences in the ‘Sharing and Privacy’ section.
3. Set the Macro Security setting to the second level ‘Disable all macros with notification’ as shown below (1).



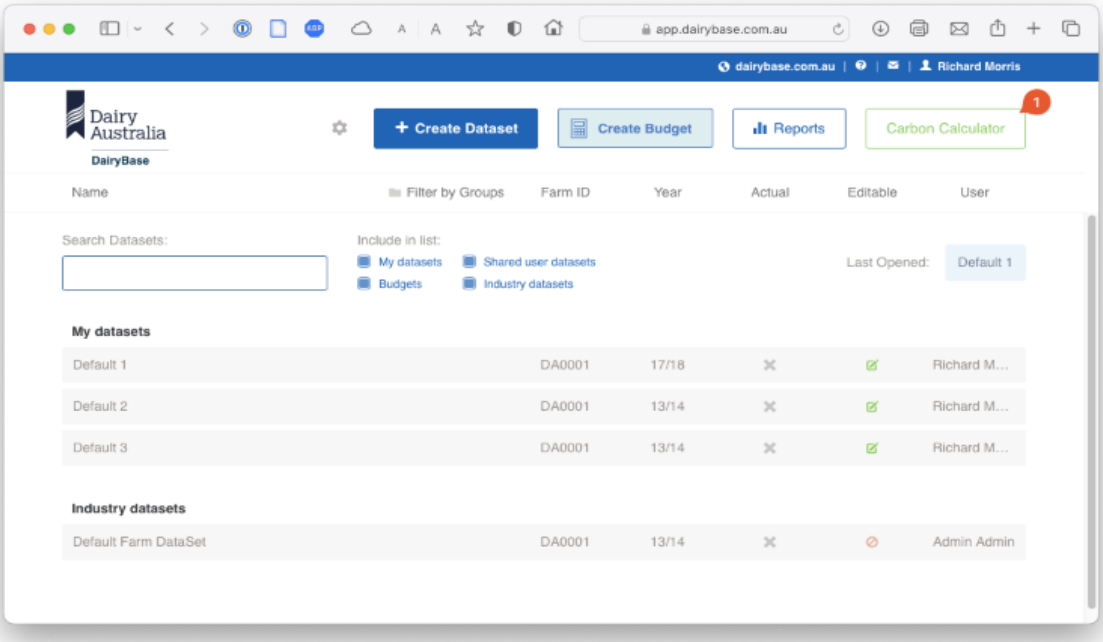
4. Exit the Preferences section by clicking on the red close button and return to the spreadsheet window. Now when a spreadsheet containing a macro opens for the first time, you will be prompted at the top of that window that macros have been disabled, but you then need to enable macros if the spreadsheet is from a trusted source (e.g. Dairy Australia), by clicking on the 'Enable Content' button as shown below. **Warning: Never enable macros in a spreadsheet unless you are sure it can be trusted! Macros in Office documents and files are a common source of malicious content.**


This workbook contains macros. Do you want to disable macros before opening the file?
Macros may contain viruses that could be harmful to your computer. If this file is from a trusted source, click Enable Macros. If you don't fully trust the source, click Disable Macros.
Learn about macros
Disable Macros
Enable Macros

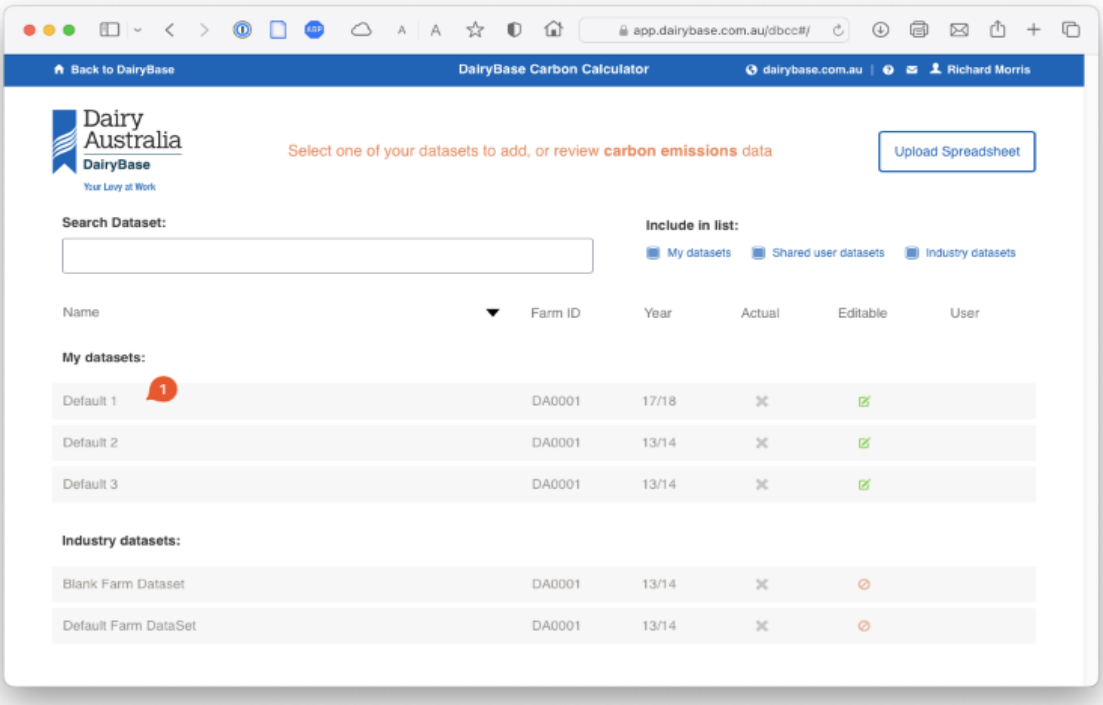
Appendix 2 DairyBase import

To import farm data from DairyBase you must first export your data from the DairyBase website (https://www.dairyaustralia.com.au/farm-business/dairybase).

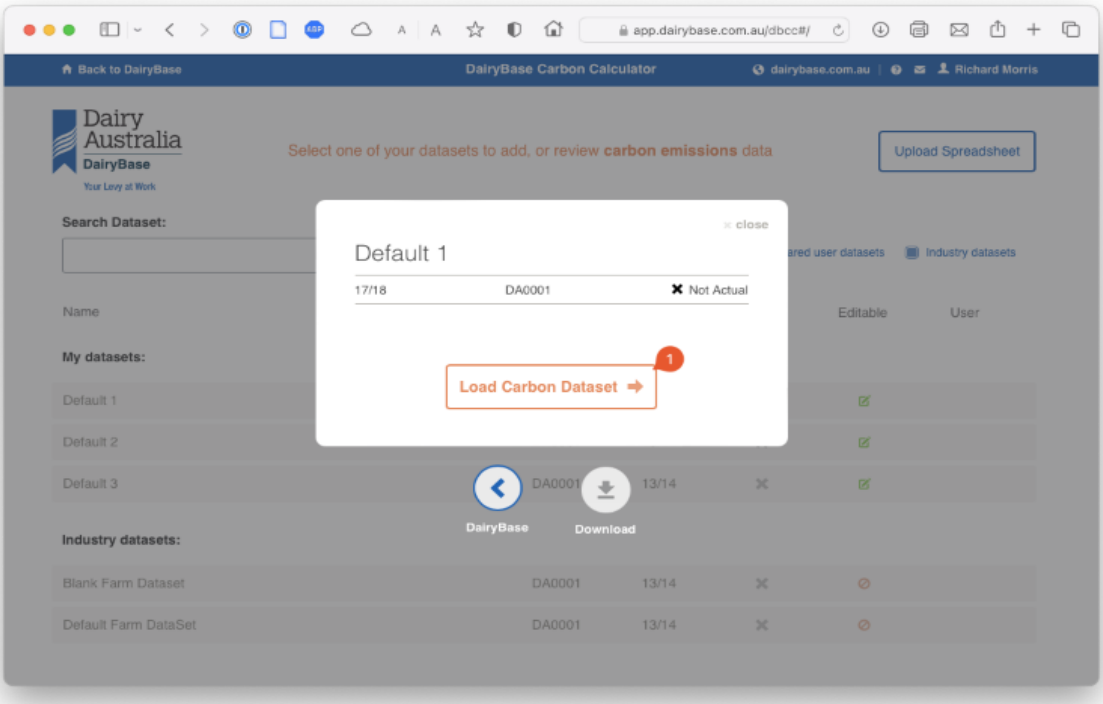
1. Login and then click on the Carbon Calculator button at the top right of the page



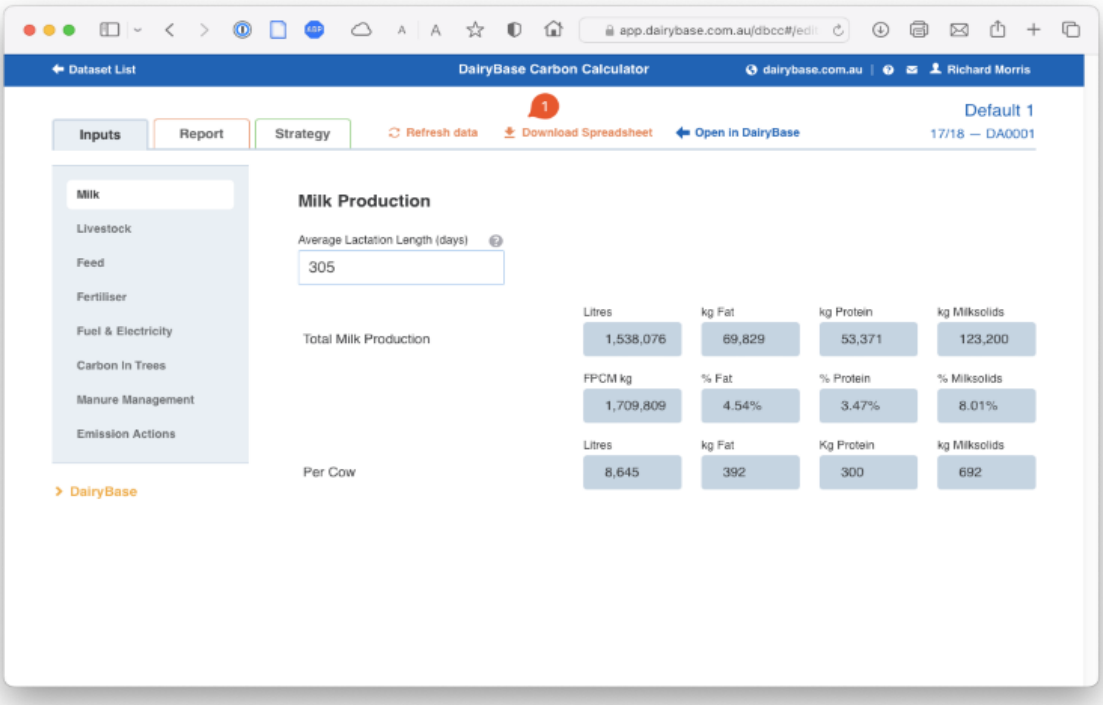
2. Select the dataset you wish to bring into ADCC by clicking on it. In the example below we are wanting to import Default 1.



3. Conform you want to load the carbon dataset by clicking on the ‘Load Carbon Dataset’ button.

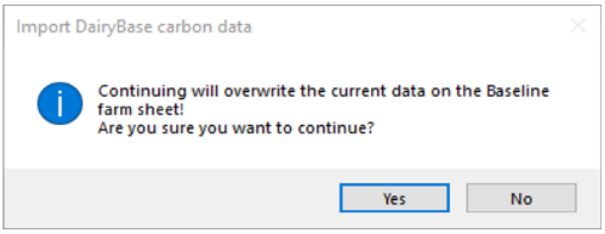


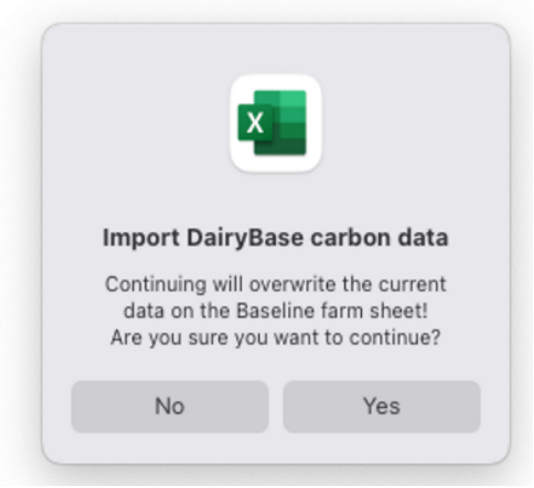
4. Once the dataset has loaded, click on the 'Download Spreadsheet’ text at the top of the window. You may need to confirm the download or select a location to save to file to. If this is the case, choose your Downloads folder on your computer.



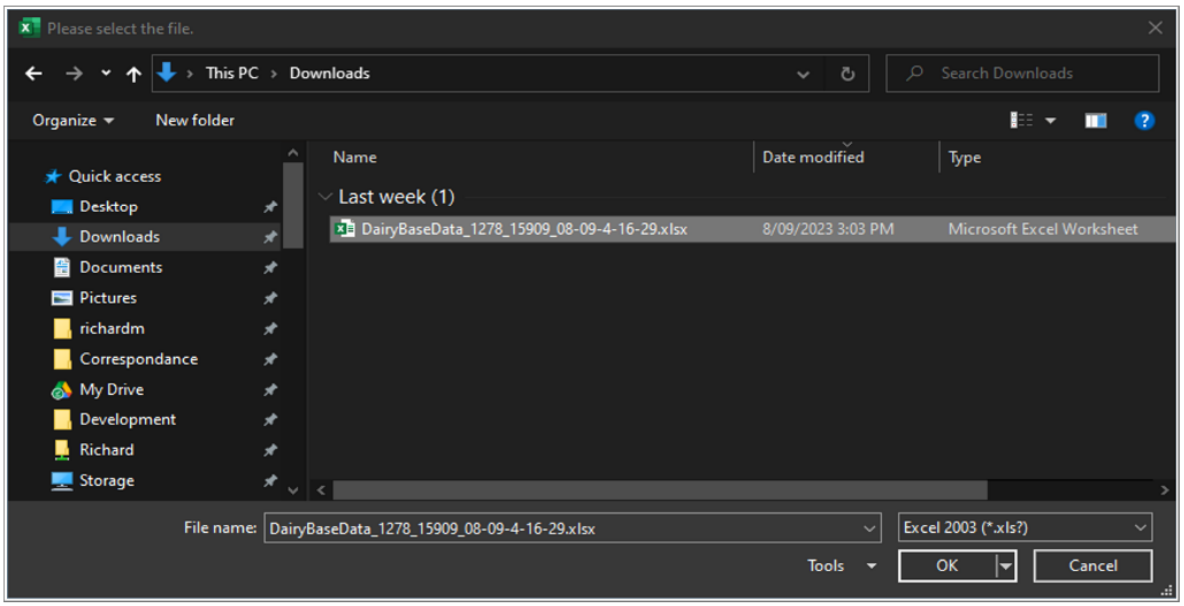
5. The download will be named something like ‘DairyBaseData_1278_17774_08-09-4-13.xlsx’ which includes a unique user ID (i.e., 1278), unique farm ID (i.e., 17774) and the date and time the file is being downloaded (8th September at 4:13am).

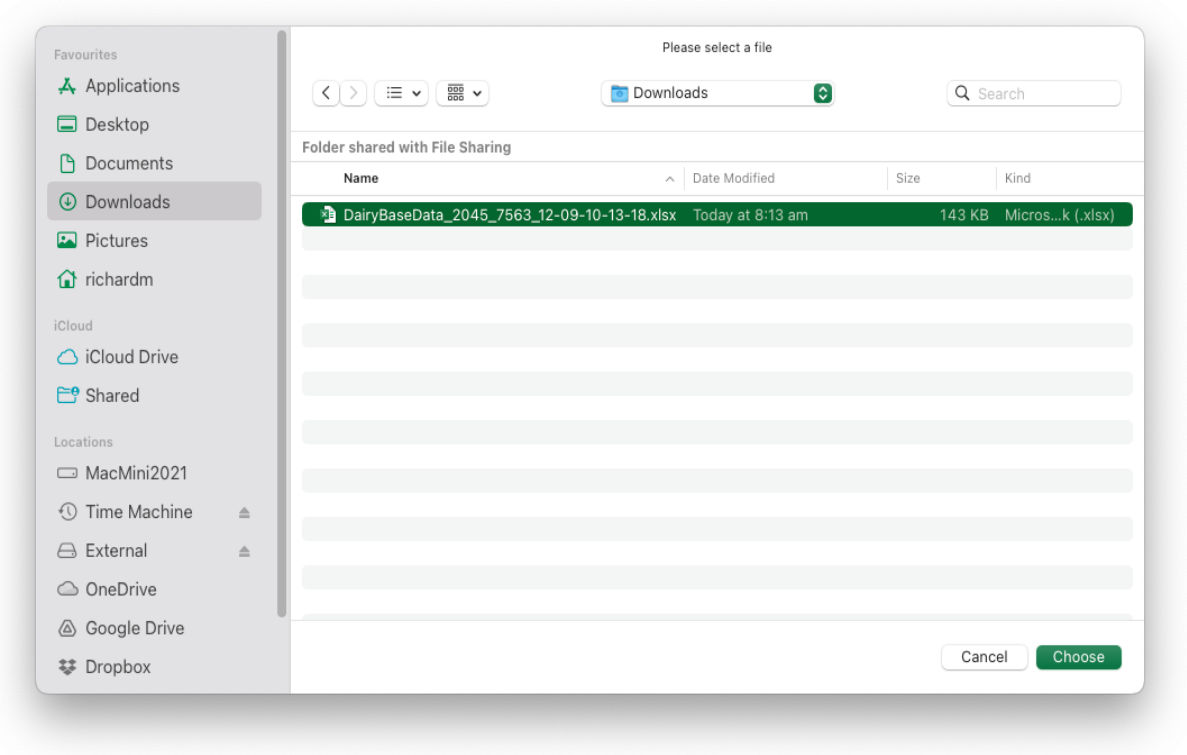
6. Now you have the DairyBase data in a file which can be imported into ADCC by progressing to the ‘Your farm’ sheet, and clicking on the ‘Import from DairyBase’ button at the top right of the sheet.
7. The importer will first ask you to confirm you wish to overwrite all existing data already entered into the ‘Your Farm’ sheet. If this is okay, click ‘Yes’ to continue.





8. A file selection window will open for you to select the DairyBase spreadsheet file you previously downloaded from the DairyBase website into your ‘Downloads’ folder. It will always be the most recent file. The first image is for Windows PCs, the second for Apple Macs. Locate the file you wish to download, then click ‘OK’ (PC) or ‘Choose’ (Mac). Your computer will now copy the data from the downloaded spreadsheet and paste into the DairyBase farm sheet. This may take a few seconds, and then the importer will tell you that the download is completed.





9. We suggest you review the net farm GHG emission estimates in DairyBase and ADCC to confirm that all data has successfully transferred across. There may be very minor (< 1%) differences in the results, especially the Heifers < 1 yr of age and milkers due to how each calculator estimates GHG emissions.

Appendix 3 Method of allocation GHG emissions to milk and meat production

At the time of developing ADCC version 5, and this accompanying manual, along with upgrading the carbon calculator within DairyBase, it became clear the International Dairy Federation (IDF, 2022) were embarking on upgrading the method of estimating the allocation of GHG emissions to milk and meat. Previous versions of the Australian calculators had allocated all GHG emissions to milk. Given the aim to maintain as many similarities as possible between these two calculators in addition to the IDF methodology, a method of estimating milk and meat net emissions, and emissions intensity was devised to best align with DairyBase, with this method reproduced for ADCC.

Step 1:

Total liveweight sold is estimate by multiplying the number of animals sold by their liveweight at point of sale. For the 'Your Farm', 115 culled cows @ 550kg = 63,250 kg, 4 bulls @ 600 kg = 2,400 kg, 215 calves sold post-weaning @ 105 kg = 22,575 kg, 10 rising 2 year old heifers @ 425 kg, and 100 Other livestock < 1 year of age @ 400 kg = 40,000kg. Meat sales totalled 132,475 kg.

Livestock class	**Number of stock sold and liveweight (kg)**	**Total LW per stock class**
Culled cows + bulls	115 @ 550kg + 4 @ 600kg	65,650
Calves sold at birth	0	0
Calves sold post-weaning	215 @ 105kg	22,575
Fattened dairy livestock (heifers)	10@ 425kg,	4,250
Fattened Other livestock	100@ 400kg	40,000
Total LW		132,475

Step 2:

Total energy demand for meat is estimated by multiplying the total liveweight of meat for each stock class by the energy required for each kg of liveweight. For example, for culled cows and bulls multiply 65,650 kg LW by 15.0 MJ/kg LW to attribute 984,750 MJ energy to cull culls. Energy attributed to Other Livestock (440,000 MJ) was deemed to automatically be attributed to meat production, as this represents where they retain non-replacement heifers and steers for the dairy beef market. The total energy demand for dairy livestock meat for each stock class was divided by dairy meat total energy demand. For example, the culled cows have an energy demand of 948,750 MJ out of a total of 1,360,525 MJ, representing 70% of total dairy meat energy demand attributed to culled cows. Likewise, a similar process is undertaken for all other dairy meat stock classes. For culled cows, 948,750 MJ out of 1,800,525 MJ represents 53% of total energy demand from all livestock meat. The same process is undertaken for all other stock classes.

Livestock class	Number of stock sold and liveweight (kg)	Total LW per stock class	Energy factor (MJ/kg LW) per stock class	Total energy demand to dairy livestock meat	% of total meat energy demand from dairy meat	Total energy demand to all livestock meat	% of total meat energy demand from all livestock meat
Culled cows + bulls	115 @ 550kg + 4 @ 600kg	65,650	15.0	984,750	72	984,750	54
Calves sold at birth	0	0	27.5	0		0	0
Calves sold post-weaning	215 @ 105kg	22,575	15.0	338,625	25	338,625	19
Fattened dairy livestock (heifers)	10@ 425kg	4,250	11.0	46,750	3	46,750	3
Fattened Other livestock	100@ 400kg	40,000	11.0			440,000	24
Total LW		132,475					
Energy demand for meat				1,370,125		1,810,525	

Step 3:

Estimate the energy attributed to milk production by multiplying total FPCM by 3.1. For the 'Your Farm', this represents 9,855,833 MJ/annum. Add this to meat energy to determine total energy demand for dairy livestock meat (11,225,958 MJ/annum), and energy demand to all livestock meat (11,665,958MJ/annum). Then divide energy demand for milk by total energy demand to dairy livestock meat to determine the % of energy attributed to milk. In this example, milk energy is 88% of total milk + dairy meat (i.e. 9,855,822 MJ / 11,225,958 MJ = 88%), while energy demand for milk, as a proportion of all milk + meat energy demand, is 85% (i.e. 9,855,833 MJ / 11,665,958MJ = 84%).

Livestock class	Number of stock sold and liveweight (kg)	Total LW per stock class	Energy factor (MJ/kg LW) per stock class	Total energy demand to dairy livestock meat	% of total meat energy demand from dairy meat	Total energy demand to all livestock meat	% of total meat energy demand from all livestock meat
Culled cows + bulls	115 @ 550kg + 4 @ 600kg	65,650	15.0	984,750	72	984,750	54
Calves sold at birth	0	0	27.5	0		0	0
Calves sold post-weaning	215 @ 105kg	22,575	15.0	338,625	25	338,625	19
Fattened dairy livestock (heifers)	10@ 425kg	4,250	11.0	46,750	3	46,750	3
Fattened Other livestock	100@ 400kg	40,000	11.0			440,000	24
Total LW		132,475					
Energy demand for meat				1,370,125		1,810,525	
Energy demand for milk				9,855,833		9,855,833	
Total energy demand for milk and meat				11,225,958		11,665,958	
% total energy to milk				88%		84%	

Step 4:

The IDF methodology (2022) refers to systems separation, where GHG emissions that can be solely attributed to the dairy or to meat production should be appropriately allocated. Given the difficulty of separating the GHG emissions from a dairy system from a dairy-beef system, we have devised a method of allocating each source of GHG emissions. ADCC attributes all electricity goes to the milk production enterprise (134 t CO_2e/annum in this example). This assumes that most electricity is either consumed in the dairy shed or for irrigating pastures fed to dairy cows.

In version 5 of ADCC, we assumed that the Scope 3 emissions for purchased grains and fodder went to the milk enterprise. However, for some farms raising all their stock, a proportion of purchased grain and fodder could go to the beef enterprise. Therefore, with version 6 of ADCC, the user determines what proportion of each purchased feed type is fed on the milking platform, assuming the balance is fed on the support or runoff block. The emissions for the milking platform proportion of Scope 3 emissions is attributed to the milk enterprise (138 t CO_2e/annum in this example), with the balance added to the General farm emissions (see below for a description of how these emissions are allocated).

All GHG emission from Other Livestock (106 t CO_2e/annum) was attributed to meat production.

Emissions from the milking herd and heifers is attributed to the milking enterprise (2,508 t CO_2e/annum in this example).

General farm emissions (N fertilisers, urea, and lime CO_2e emissions, pre-farm embedded emissions from fertilisers and supplementary feed fed on the support or runoff block, Scope 1 and 3 emissions from fuel, and carbon sequestered in trees), totalling 652 t CO_2e/annum in this example, could not be separated between milk production and meat production. A proportion of these emissions were attributed to milk production, based on the proportion of milk energy to total milk and meat energy, i.e. 84% in this example, thus 551 t CO_2e/annum, with the balance 16% of general farm GHG emissions (101 t CO_2e/annum) attributed to meat production.

Therefore, milk production was allocated 3,026 t CO_2e (i.e. sum of 2,202t CO_2 from the milking herd related livestock, 273 t CO_2e from electricity and milking platform-fed purchased concentrates and fodder, and 551 t CO_2e from general farm emissions) while meat production was allocated the balance 513 t CO_2e (i.e. sum of 106 t CO_2e from Other livestock, balance of 306 t CO_2e from dairy herd related livestock (culled cows, bulls and replacement heifers no longer retained), and balance of 101 t CO_2e from general farm GHG emissions). Milk and meat production GHG emissions were then divided by total GHG emissions to determine the percentage of emissions allocated to milk and meat, at 85.5% and 14.5%, respectively.

Livestock class	Number of stock sold and liveweight (kg)	Total LW per stock class	Energy factor (MJ/kg LW) per stock class	Total energy demand to dairy livestock meat	% of total meat energy demand from dairy meat	Total energy demand to all livestock meat	% of total meat energy demand from all livestock meat	GHG emissions (t CO_2e/annum)
Culled cows + bulls	115 @ 550kg + 4 @ 600kg	65,650	15.0	984,750	72	984,750	54	
Calves sold at birth	0	0	27.5	0		0	0	
Calves sold post-weaning	215 @ 105kg	22,575	15.0	338,625	25	338,625	19	
Fattened dairy livestock (heifers)	10@ 425kg	4,250	11.0	46,750	3	46,750	3	
Fattened Other livestock	100@ 400kg	40,000	11.0			440,000	24	
Total LW		132,475						
Energy demand for meat				1,370,125		1,810,525		
Energy demand for milk				9,855,833		9,855,833		
Total energy demand for milk and meat				11,225,958		11,665,958		
% total energy to milk				88%		84%		
Milk only emissions (electricity and purchased grain + fodder fed on milking platform)								273
Meat only emissions (Other livestock)								106
Dairy livestock emissions (milk/meat breakdown)								2,508 (2,201/306)
General farm emissions (milk/meat breakdown)								652 (551/101)
Total emissions								3,540
Total milk GHG emissions								3,026
Total meat GHG emissions								513
% total CO_2 allocated milk								85.5%
% total CO_2 allocated meat								14.5%

Step 5:

Milk allocated GHG emissions were then divided by total milk production to estimate the EI for milk production. In this example, 3,026 t CO_2e was divided by 3179.3 t FPCM, resulting in an EI of 0.95 kg CO_2e/kg FPCM. Total meat allocated GHG emissions were then divided by total meat produced to estimate the EI of meat production. In this example, 513 t CO_2e was divided by 132.5 t liveweight, for an EI of 3.9 kg CO_2e/kg liveweight.

While not visible to users of ADCC, there is a further series of steps to estimate the EI of meat production for each stock class. The emissions for each stock class is then calculated as dairy livestock GHG emissions x (1- total energy demand to dairy livestock meat %) x (% of total energy demand for meat from dairy meat + general farm GHG emissions) x (1- Total energy demand to all livestock meat %) x % of total energy demand for meat from all livestock meat.

In this example above, the tonnes of CO_2 allocated to cull cows was 2,508 t CO_2e x (1-88%) x 72% + 652 t CO_2e x (1-84%) x 54%, equivalent to 275 t CO_2e. This was then converted into kg of CO_2e, and then divided by total kg of meat from cull cows and bulls (65,650 kg), to estimate an EI of 4.2 kg CO_2e/kg LW. The same process is undertaken for all other stock classes. For this example, the EI was 4.2 kg CO_2e/kg LW for weaned calves, 3.1 kg CO_2e/kg LW for fattened dairy livestock, and 3.3 kg CO_2e/kg LW for fattened Other livestock. This illustrates that while the overall meat EI was 3.8 kg CO_2e/kg LW, there was variation between stock classes.

	Total emissions (t CO_2e/annum)	**Total product (t FPCM)**	**EI milk (kg CO_2e/kg FPCM**	**Total product (t LW)**	**EI meat (kg CO_2e/kg LW)**
Milk	3,026	3,179.3	0.95		
Meat	513			132.5	3.9
Culled cows and bulls	275			65.6	4.2
Calves at birth	0			0	0
Calves weaned	995			22.6	4.2
Fattened dairy livestock	13			4.3	3.1
Fattened other livestock	131			40	3.3

Appendix 4 National and regional emission sources

Typical regional, state, country-wide, and level of grain feeding percentage of GHG emissions, based on several years of DairyBase data (Dairy Farm Monitor Project (2019-20 to 2023-24) and Queensland Dairy Accounting Scheme from 2022-23 to 2023-24; noting that for the Australian and grain feeding rate results, the data for QLD is from 2019-20 to 2023-24). Note that rounding may result is slightly inaccurate results, such as 0% N_2O emissions from manure storage and spread for Gippsland. The result is 0.5% but rounds down to 0%.

Source/sink GHG emissions	Australia-wide	Victoria	VIC- Gippsland	VIC- Northern	VIC- South West	New South Wales	NSW- North	NSW- South
Enteric methane	62%	59%	61%	59%	58%	659	61%	58%
Waste methane	9%	10%	9%	11%	8%	10%	7%	11%
N_2O direct grazing	3%	3%	4%	3%	3%	3%	3%	3%
N_2O from manure storage & spread	1%	1%	0%	1%	1%	1%	1%	2%
Indirect N_2O from N waste	4%	3%	4%	3%	3%	4%	4%	3%
Direct N_2O from N fertiliser	3%	3%	3%	2%	4%	3%	4%	3%
Indirect N_2O from N fertiliser	2%	2%	2%	1%	2%	2%	2%	1%
Electricity	2%	3%	3%	3%	4%	3%	4%	3%
Fuel	2%	2%	2%	3%	3%	3%	4%	3%
Urea & Lime	2%	2%	2%	1%	2%	2%	3%	2%
Concentrates	5%	5%	5%	4%	5%	5%	5%	5%
Fodder	2%	2%	1%	3%	1%	2%	1%	2%
Fertiliser	5%	5%	6%	4%	8%	6%	7%	5%
Trees	-1%	-1%	-2%	0%	-1%	-3%	-5%	-1%
No. farms for each column mean	1020	400	125	150	125	184	93	91

Typical regional, state, country-wide, and level of grain feeding percentage of GHG emissions, based on several years of DairyBase data (Dairy Farm Monitor Project (2019-20 to 2023-24) and Queensland Dairy Accounting Scheme from 2022-23 to 2023-24; noting that for the Australian and grain feeding rate results, the data for QLD is from 2019-20 to 2023-24). Note that while there may be trees on QLD farms, this data has yet to be captured and as such, the values for all sources may be slightly different if we could account for tree carbon sequestration.

Source/sink GHG emissions	Queensland	QLD-North	QLD-South	South Australia	Tasmania	Western Australia	Low grain[1]	Med grain[1]	High grain[1]
Enteric methane	59%	62%	58%	63%	66%	61%	65%	63%	60%
Waste methane	14%	13%	14%	5%	8%	8%	8%	8%	9%
N_2O direct grazing	3%	3%	2%	4%	4%	4%	4%	4%	3%
N_2O from manure storage & spread	2%	1%	2%	1%	0%	1%	1%	1%	1%
Indirect N_2O from N waste	4%	4%	4%	4%	4%	4%	4%	4%	4%
Direct N_2O from N fertiliser	2%	2%	2%	3%	3%	3%	3%	3%	3%
Indirect N_2O from N fertiliser	1%	1%	1%	1%	2%	2%	2%	2%	2%
Electricity	0%	0%	0%	2%	1%	2%	1%	2%	3%
Fuel	3%	2%	3%	4%	1%	3%	1%	2%	3%
Urea & Lime	1%	1%	1%	1%	2%	1%	2%	2%	2%
Concentrates	5%	5%	5%	5%	4%	5%	3%	4%	5%
Fodder	1%	2%	1%	2%	1%	1%	1%	1%	2%
Fertiliser	4%	3%	4%	5%	5%	6%	5%	5%	5%
Trees	0%	0%	0%	0%	-1%	-1%	0%	-1%	-1%
No. farms for each column mean	94	24	70	78	144	121	75	464	638

[1] Low grain feeding = < 1 tonne DM/cow.lactation, medium grain feeding = 1-2 tonnes DM/cow.lactation, high grain feeding = > 2 tonnes DM/cow.lactation determined by dividing total grain purchased by the number of milking cows.

Typical regional, state, country-wide, and level of grain feeding emission intensities, based on several years of DairyBase data (Dairy Farm Monitor Project and Queensland Dairy Accounting Scheme from 2019-20 to 2023-24).

Source/sink GHG emissions	Australia-wide	Victoria	VIC- Gippsland	VIC- Northern	VIC- South West	New South Wales	NSW- North	NSW- South
Milk EI	0.91	0.90	0.90	0.87	0.92	0.94	0.93	0.92
Meat EI	5.02	4.86	4.81	4.71	5.08	4.81	4.80	4.95
Milk MS EI	12.72	12.46	12.48	12.16	12.81	13.28	13.10	12.99
Enteric methane	0.56	0.54	0.55	0.54	0.54	0.56	0.57	0.56
Waste methane	0.08	0.08	0.08	0.09	0.08	0.08	0.07	0.09
N_2O direct grazing	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
N_2O from manure storage & spread	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01
Indirect N_2O from N waste	0.03	0.02	0.03	0.02	0.03	0.03	0.03	0.02
Direct N_2O from N fertiliser	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Indirect N_2O from N fertiliser	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01
Electricity	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.03
Fuel	0.02	0.02	0.01	0.02	0.02	0.03	0.03	0.03
Urea & Lime	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02
Concentrates & grains	0.04	0.04	0.04	0.04	0.05	0.04	0.05	0.05
Fodder	0.01	0.02	0.01	0.03	0.01	0.02	0.01	0.02
Fertiliser	0.05	0.04	0.05	0.03	0.06	0.05	0.06	0.04
Milk to meat ratio	0.87	0.88	0.88	0.89	0.87	0.86	0.86	0.88
Meat to milk ratio	0.13	0.12	0.12	0.11	0.13	0.14	0.14	0.12
No. farms for each column mean	1020	400	125	150	125	184	93	91

Typical regional, state, country-wide, and level of grain feeding emission intensities, based on several years of DairyBase data (Dairy Farm Monitor Project and Queensland Dairy Accounting Scheme from 2018-19 to 2022-23). Note that there was only electricity and fuel data for the QLD datasets in 2022-23 and 2023-24. Thus, the EIs will also be slightly lower than expected for the three Queensland columns.

Source/sink GHG emissions	Queensland	QLD-North	QLD-South	South Australia	Tasmania	Western Australia	Low grain[1]	Med grain[1]	High grain[1]
Milk EI	1.05	1.06	1.04	0.84	0.86	0.93	0.96	0.89	0.92
Meat EI	6.30	7.07	6.03	4.46	4.71	5.49	5.61	4.78	5.13
Milk MS EI	14.72	15.07	14.60	11.78	11.86	13.13	13.29	12.35	12.94
Enteric methane	0.63	0.67	0.62	0.54	0.58	0.57	0.63	0.55	0.56
Waste methane	0.13	0.13	0.13	0.04	0.07	0.08	0.08	0.08	0.08
N_2O direct grazing	0.03	0.04	0.03	0.03	0.03	0.03	0.04	0.03	0.03
N_2O from manure storage & spread	0.02	0.01	0.02	0.01	0.00	0.01	0.00	0.01	0.01
Indirect N_2O from N waste	0.03	0.02	0.03	0.02	0.02	0.03	0.03	0.03	0.03
Direct N_2O from N fertiliser	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.03
Indirect N_2O from N fertiliser	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01
Electricity	0.01	0.00	0.01	0.02	0.00	0.02	0.02	0.02	0.03
Fuel	0.03	0.02	0.03	0.03	0.01	0.03	0.02	0.02	0.03
Urea & Lime	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.02
Concentrates and grains	0.05	0.05	0.05	0.04	0.04	0.05	0.02	0.04	0.05
Fodder	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.02
Fertiliser	0.05	0.04	0.05	0.04	0.04	0.05	0.05	0.04	0.05
Milk to meat ratio	0.84	0.83	0.84	0.88	0.87	0.81	0.84	0.88	0.86
Meat to milk ratio	0.16	0.17	0.16	0.12	0.13	0.19	0.16	0.12	0.14
No. farms for each column mean	94	24	70	78	144	121	75	464	638

[1] Low grain feeding = < 1 tonne DM/cow.lactation, medium grain feeding = 1-2 tonnes DM/cow.lactation, high grain feeding = > 2 tonnes DM/cow.lactation assuming all grain is fed to the milking cow.

1800 004 377
enquiries@dairyaustralia.com.au
dairyaustralia.com.au