

Australian Dairy Carbon Calculator Manual

Version 5.2

Full documentation

April 2024



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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 1,775 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. Many thanks to Richard Morris for building this new functionality.

Lastly, a huge thank you to everyone who took the time to review this manual.

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1. Australian Dairy Carbon Calculator Manual

The Australian Dairy Carbon Calculator manual contains four theme areas:

- Carbon accounting (sections 1-4),
- Australian Dairy Carbon Calculator (section 5),
- Benchmarking of Dairy Farm Monitor Project data (section 6), and
- GHG adaptation options explored in the Carbon Offset Scenario Tool (section 7)

This version of the manual contains all sections. We have also separated each of these theme area into four separate stand-alone documents. These can be downloaded from the Dairy Australia website if users which 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.dccew.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 (CO₂), methane (CH₄), and nitrous oxide (N₂O) are multiplied by the current global warming potential (GWPs), as reported in NGGI.

The Australian NGGI methodology has amended the global warming potentials (GWP₁₀₀) for methane (CH₄) and nitrous oxide (N₂O) to align with the 2014 IPCC Fifth Assessment Report (AR5) values of 28 and 265, respectively. At the timing of the upgrade of ADCC from version 5.1 to 5.2, there has been a new IPCC Assessment Report released (AR6) which now separates CH₄ 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 GWP₁₀₀ values are 30 and 27 for fossil and non-fossil derived CH₄, respectively, and 273 for N₂O 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.

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 CH₄ and N₂O. 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 CH₄ emissions. Examples could include breeding animals with a lower CH₄ production per kg of dry matter intake (DMI), inclusion of CH₄ inhibitors (e.g. 3-nitrooxypropanol) or extended lactations to reduce the number of replacement animals required,
3. Feedbase management to reduce N₂O emissions. Examples could include the use of a nitrification inhibitor to reduce N₂O emissions from urine patches, and
4. Abatement strategy farm where one or more aspects of the baseline farm can be altered to reduce CH₄ and/or N₂O 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 quantify 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
CH₄	Methane
CO₂	Carbon dioxide
CO₂e	Carbon dioxide equivalents (CO ₂ e) 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 voluntary carbon credit scheme, formerly known as the CFI and subsequently the ERF
DFMP	Dairy Farm Monitor Project
DGAS	Dairy Greenhouse gas Abatement Strategies calculator, the original name for ADCC
Direct N₂O	Nitrous oxide lost to the environment from deposition of urine, dung, effluent, and nitrogen-based fertilisers (see indirect N ₂ O)
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 different 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 ₂ O)
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
GWP₁₀₀	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 N₂O	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 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
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)
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
NH₄	Ammonium
Nitrous oxide	Nitrous oxide (N ₂ O) is a GHG that is 265 times more potent than carbon dioxide, based on the IPCC AR5 report. N ₂ O 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
N₂O	Nitrous oxide
NO₃	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 2030¹ 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 essentially represent lost 'energy' from the farm system. For example, reducing enteric CH₄ 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 N₂O 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/land-water-and-climate>) also contains a range of resources 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 (CO₂)
- methane (CH₄)
- nitrous oxide (N₂O)
- sulphur hexafluoride (SF₆)
- other hydrofluorocarbons and perfluorocarbons

The main emissions from agricultural production are CO₂, CH₄ and N₂O (Figure 1; reproduced with modifications courtesy of Agriculture Victoria). Greenhouse gas emissions are measured in CO₂ equivalents (CO₂e) 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 CO₂, when reported on a 100-year timeframe (GWP₁₀₀). In contrast, N₂O has a GWP₁₀₀ of 265 times that of CO₂. The most recent 2023 IPCC Sixth Assessment Report (AR6) now separates CH₄ 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 N₂O has altered to 273. As 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 GWP₁₀₀ method, particularly around how CH₄ is handled (IPCC 2014; Lynch *et al.* 2020). Methane breaks down into biogenic CO₂ and water vapour after around 10–14 years. The warming effect of CH₄ during these years is significantly higher, at around 80+ times more potent than CO₂ 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 CH₄ under specific scenarios.

In the future, new methods, such as GTP, may gain more traction and become standard international practice. We note that these GWP₁₀₀ values are periodically updated in response to new science, and for the purposes of ADCC and this manual, the AR5 GWP₁₀₀ values of 28 and 265 for CH₄ and N₂O have been applied to remain aligned with the Australian Government inventory, as of July 2023.

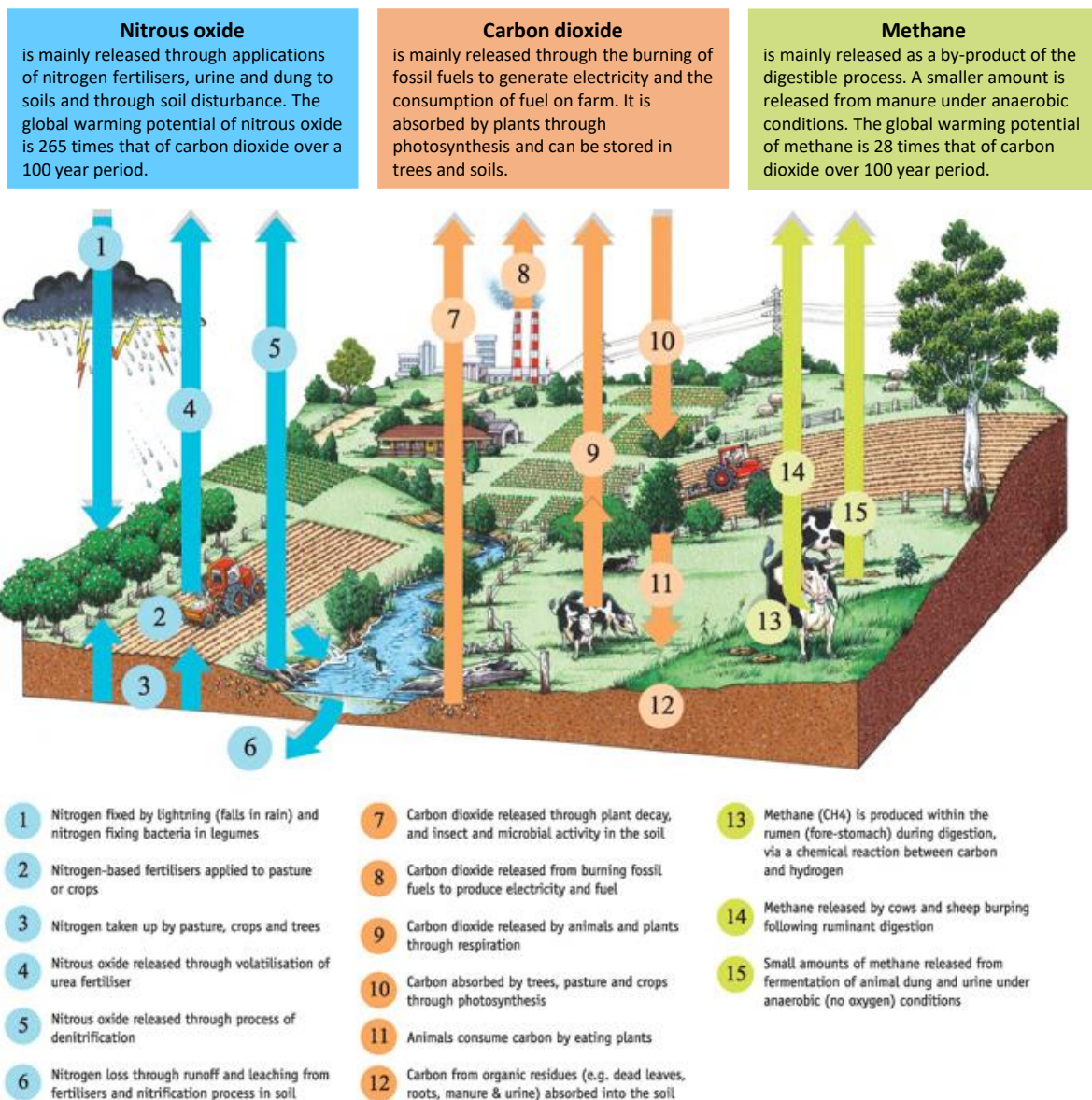


Figure 1. Sources of major dairy farm greenhouse gas emissions (Courtesy of Agriculture Victoria (2022), adapted with updated GWPs).

4.2. Methane

Enteric CH₄ 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 CO₂ to form CH₄. Enteric CH₄ 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 CH₄ production as 20.7 g CH₄/kg dry matter intake (DMI; Charmley *et al.* 2016), equivalent to ~ 3.8 t CO₂e/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 CH₄ emissions in Australia are relatively low. Most dung and urine are deposited onto pastures as animals are grazing, compared to housed systems in Europe and North America. ADCC uses state-based data to ascertain what proportion of waste is handled 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 CH₄ 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 handled under these feeding regimes, to give a more accurate reflection of waste CH₄ 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 N₂O are largely a result of two soil microbial processes, nitrification, and denitrification. Nitrification is an aerobic process that oxidises ammonium (NH₄⁺) to nitrate (NO₃⁻), with denitrification of N₂O produced as a by-product. Denitrification is also an anaerobic process that reduces nitrate into dinitrogen (N₂), with N₂O 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 N₂O from animal waste and fertilisers are temperature, water-filled pore space (WFPS), level of organic carbon, soil pH, and soil NO₃ (Whitehead 1995). Soil NO₃ levels and soil aeration (WFPS) have been identified as the most likely key factors affecting N₂O emissions from grazing systems (Eckard *et al.* 2010). In addition to direct losses of N₂O as described above, a proportion of N lost to the environment through leaching and/or runoff of NO₃ and ammonia (NH₃) 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 N₂O emissions.

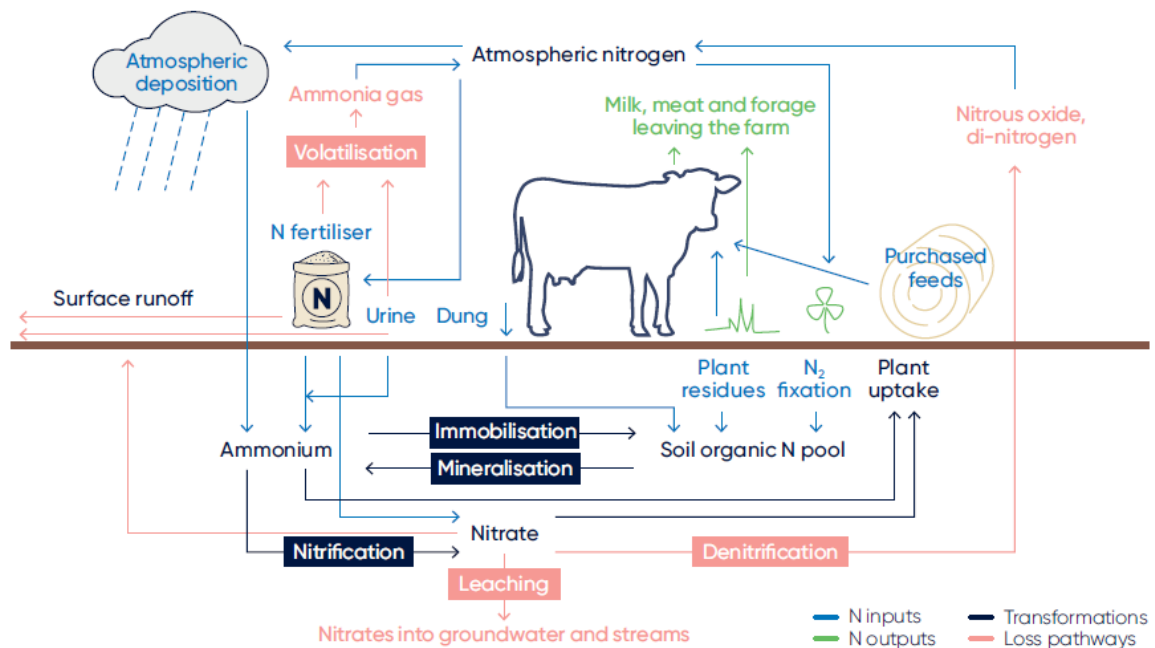


Figure 2. Simplified nitrogen cycle of a grazed dairy pasture (Source: Dairy Australia Fert\$mart Nitrogen Pocket Guide).

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 CO₂ from the atmosphere. When applied to pastures and crops, this CO₂ is released back into the atmosphere. Lime undergoes a similar process as urea, releasing CO₂ to the atmosphere when applied to pastures and crops. Carbon dioxide emissions (mainly CO₂ but also smaller amounts of CH₄ and/or N₂O) arise from the manufacturing and transporting of key farm inputs, such as fertilisers and feeds. Soils also respire CO₂ 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 CO₂ 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 CO₂ 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 findings are then incorporated into methodologies (i.e. NNGI) to estimate GHG emissions and carbon sequestration. An example of this is the equation to estimate enteric CH₄, 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 CH₄ emissions. For example, Agriculture Victoria's Ellinbank dairy research facility is considered the 'Gold-Star' for measuring enteric CH₄ emissions. Any results from diets that were considered to inhibit the reduction in enteric CH₄ (e.g. high in dietary fat or tannins) were omitted from the meta-analysis. This resulted in > 1,000 datapoints to develop the NNGI relationship between intake and CH₄ production, at 20.7 g CH₄/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 CO₂e/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 CO₂e per kg milksolids (MS) or kg CO₂e 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 globally².

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 CO₂e/kg energy-corrected milk when 100% of emissions were allocated to milk. However, EI could be as low as 0.63 CO₂e/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 CH₄ emissions from livestock), feed production (e.g. N₂O emissions from fertiliser inputs), and manure management (e.g. CH₄ and N₂O emissions from dung and urine). It also includes emissions associated with key inputs, commonly known as pre-farm embedded 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 N₂O 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 CH₄ emissions, N₂O emissions from animal waste and N-based fertilisers, CO₂ emissions from lime and urea applications on farm, as well as CO₂ emissions from the consumption of fuel in farm vehicles and machinery.

Scope 2 GHG emissions are the CO₂ 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 CO₂e 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 neutrality or net zero occurs when total GHG emissions (sum of all three Scope emission) equals the amount of carbon sequestered in soils, and/or tree vegetation plus any carbon offset credits purchased and relinquished by the farm business for the year of assessment. Note that a net zero carbon footprint does not necessarily mean absolute zero GHG emissions. A farm could still be a high emitter of GHGs but be net zero if the amount of carbon sequestered on-farm plus purchased offsets either equals GHGs emitted (i.e. carbon neutral/net-zero) or outweighs GHG emissions (beyond net zero) (Figure 3).

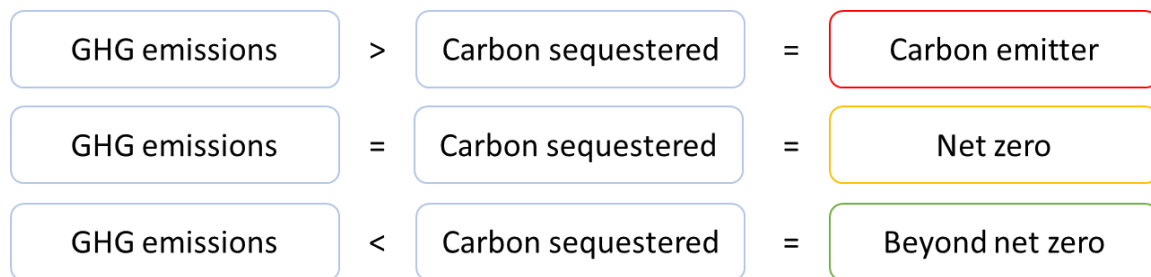


Figure 3. A farm remains a carbon emitter (red outcome) when GHG emissions are greater than carbon sequestered. A farm is carbon neutral/net zero (orange outcome) when the amount of carbon sequestered is equal to GHG emissions. The best outcome is when the amount of carbon sequestered is greater than 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 CH₄ 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 CH₄ gas (a short-term GHG) the same as we do CO₂ and N₂O (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 CH₄ is around 10-12 years, compared to 100+ years for the other two gases. Over a much shorter timeframe, the GWP of CH₄ is significantly higher (~ 84 times more potent than CO₂). A tonne of CH₄ emitted today will break down into CO₂ 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 CH₄ 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 CO₂ and CH₄ emissions on global warming over time. So if we (globally) can stabilise CH₄ production, the tonne produced today replaces the tonne produced 10-12 years ago, thus the net change in CH₄ emissions and global warming attributed to CH₄ will flatline (middle set of graphs). In contrast, even if we were to stabilise CO₂ production today, the tonne of CO₂ 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 CH₄ 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 CH₄ 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.

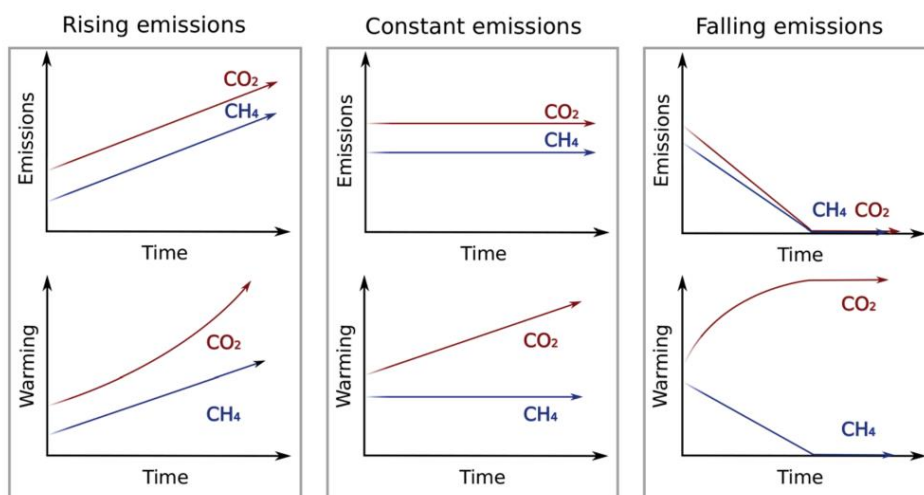


Figure 4. Illustration of the effect of rising, constant or falling carbon dioxide and methane emissions on global warming over time (Source: <https://clear.ucdavis.edu/explainers/why-methane-cattle-warms-climate-differently-co2-fossil-fuels>, accessed March 2022).

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

When urea is manufactured, it takes CO₂ 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 CO₂e.

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 NNGI methodology (Australian Government, 2023). 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#.Yfyihd9Bwnl>). 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 NNGI 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 7). ADCC also allows users to compare the effect of the changing NNGI methodology on baseline farm emissions. For example, for the farm example used in sections 5 and 6, the 1990 methodology results were 3,242 t CO₂e/annum, increasing slightly to 3,289 t CO₂e/annum with the 2015 methodology, increasing substantially to 3,582 t CO₂e/annum with the 2022 methodology. 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/resource-repository/2023/01/30/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 versions 5.1 and 5.2 of ADCC?

There have been a series of updates/amendments between ADCC versions 5.1 and 5.2. These are listed towards row 140 of the Introduction tab, and include:

- Implementation of a pathway to import a DairyBase farm dataset into ADCC, including how to implement macros which everyone will need to do, not just those importing a dataset from DairyBase,
- Ability to clear all data entry for the baseline farm tab,
- Clarifying that electricity inputs are those purchased from the grid only; we are no longer subtracting any home-generated renewable energy that is exported back into the grid,
- Altered the design of the tree carbon sequestration section, including removing the data entry drop-down list for soils and disengaged the Vlookup function to determine soil type for sequestration estimates. There was only a very small number of regions by tree species interaction that resulted in slight difference in results (formulas still intact if we decide to reinstate in the future),
- Built in the option to explore up to four areas of tree carbon sequestration,
- Fixed the cell protection not allowing to pick the other option from the drop-down list and altered to being a white cell to identify that this is a data entry cell,
- Amended a few typing errors,
- Amended an equation error for non-state based manure management for livestock when heifers manure is stored in a sump/disperal system prior to spreading onto pastures,
- Included industry comparison emissions intensities, broken down into each source, per kg FPCM, kg MS and kg LW and ratio of emissions to milk vs meat,
- Altered the *Reduced enteric methane through breeding or management* scenario, re-naming it *Reduced enteric methane and/or improved milk production without changes to intake* scenario (tab name Reduce CH₄ and or Increase milk). Here we can look at multiple options such as feeding an additive to reduce enteric CH₄ emissions (e.g. Asparagopsis) or a CH₄-reduction vaccine which may or may not increase milk production, or genetic improvement to increase milk production without a change in enteric CH₄ production, or the inclusion of high sugar ryegrass pastures to improve milk production without a change in enteric CH₄,
- Changed the password to unprotect sheets to now be Dairy_ADCC,
- Changed cell colouring for the fertiliser section so that if the 'tonnes of element per annum' option is selected from the drop-down list, the area of pastures and crops goes from white to purple to signify that this section does not require data entry. The cells only remain white, to indicate data entry required, if the 'kg of element per ha per annum' option is selected from the drop-down list,
- Initially we allocated all Scope 3 emissions for purchased fodder to the milk enterprise when determining emissions allocated to milk vs meat. Discussions with the DFMP team in

particular, stated that for some WA farms in particular, and could be across all regions, farmers may buy in fodder for their Other Livestock classes. To accommodate this, we have built in a new question which asks users to define what percentage of purchased fodder is allocated to dairy, with a default of 100% if the cell is left blank.

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 ~ 5.0 to 5.8 t CO₂e/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 CH₄ 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 CO₂e from direct and indirect N₂O 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 N₂O losses. The NGGI equations have taken a national approach to estimate N₂O losses.

The enteric CH₄ 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 CH₄ production by approx. 0.16 t CO₂e/annum based on the baseline 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 7.2). If used in this way, this intervention will not reduce net farm GHG emissions, only emissions intensity.

Several supplementary feeds may reduce enteric CH₄ production. For example, feeding a source of high dietary fat can reduce enteric CH₄ by 3.5% for each 1% increase in overall diet fat content (see Sections 6.4 and 6.5). Another example is a comparison made by Moate *et al.* (2017), finding dairy cattle fed wheat produced significantly less enteric CH₄ than if they were fed either barley or maize grain. The baseline farm 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 CH₄ 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 lanceolata*) (Min *et al.* 2020; Simon *et al.* 2019)). These species, to varying degrees, can reduce enteric CH₄ production. In addition, some of these species can also reduce N₂O 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 17).

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 of this information at hand. The task will take 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 new feature of version 5.2 of ADCC is the ability to import a DairyBase farm system file into the baseline sheet of ADCC (see section 5.6 for further details). To facilitate this new feature, we have needed to introduce macros to run this import. Therefore, when downloading version 5.2, saving it to your computer and then opening it for the first time, you may 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 sheet (scroll down to row 155).

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.



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

At the bottom left-hand side of the Introduction sheet, there's a list of changes made versions. The current version 5.2 contains both a list of changes between version 4 and version 5.1, and more recently the upgrades with version 5.2.

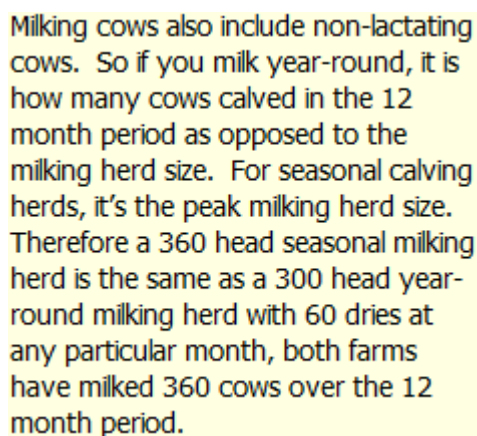
We have purposely protected each sheet to maintain integrity of the equations. We have also hidden all the 'working' components of each sheet. If you wish to unprotect worksheet(s) to view the working components, locate the 'Review' tab in excel, click on 'Protect Sheet', and type in the password Dairy_ADCC (case sensitive). You can then unhide the rows to access the working calculation area. Only unprotect the worksheet(s) if you are confident that you won't alter any of the equations.

5.5. Baseline farm data entry

The "Baseline farm" sheet 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 "Baseline farm" sheet for the first time, all cells will be blank. We have created an "Example baseline

farm” sheet to illustrate a typical farm (same as used in sections 5 and 6 in this manual) as a reference point to understand the data entry required.

Many of the headings or questions asked will have a note in the form of a red triangle in the top right corner. If you place your mouse over the cell where the heading/question is, a note will appear, giving additional information. For example, when you hover your cursor over the Milking Cows heading, the message in Figure 6 appears.



Milking cows also include non-lactating cows. So if you milk year-round, it is how many cows calved in the 12 month period as opposed to the milking herd size. For seasonal calving herds, it's the peak milking herd size. Therefore a 360 head seasonal milking herd is the same as a 300 head year-round milking herd with 60 dries at any particular month, both farms have milked 360 cows over the 12 month period.

Figure 6. Screenshot of the Milking Cows help message.

In most instances, you will need to enter data in each of the white cells. Some white cells require numbers, while others will have a drop-down list. You need to select the most suitable option for your farm assessment. Note: the cell with the drop-down list for when calves are sold is purple as opposed to white.

The only exceptions where you may not need to enter data into white cells for the baseline farm are:

- If you enter fertiliser using the ‘tonnes of element per annum’ option rather than the ‘kg of element per ha per annum’ option (see *Step five*),
- When 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 sheet. Figure 7 is a screenshot of the farmer’s details. Selecting your state within Australia is critical to determining how the manure (dung and urine) is handled 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 5.4). Users can select either their region (Victoria, New South Wales, and Queensland broken down into several 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.

Owner or sharefarmer ID	Bill and Wendy Smith	Supplier Number	256758T1
Address	1234 Main Rd, Colac, VIC 3250	Year reviewed	2020/21
Choose your state in Australia	Victoria	Choose your region/ farm system comparison	Victoria- South West

Figure 7. Farmer details section on the “Baseline farm” sheet. This farm is in Victoria, to estimate waste emissions, and the results graph will compare this farm with the Victoria- South West average.

Step two: Livestock numbers, liveweights, and sales data

Livestock numbers

The largest source of on-farm GHG emissions is enteric CH₄. 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 8, 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. $100 \text{ steers} \times 9 \text{ months} + 0 \text{ steers} \times 3 \text{ months} = 900 \text{ steers} / 12 \text{ months} = 75 \text{ steers}$). 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. $100 \text{ 1-2 yr old steers} \times 12 \text{ months} + 100 \text{ 2- 3 yr old steers} \times 2 \text{ months} = 1400 \text{ steers} / 12 \text{ months} = 117 \text{ steers}$).

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
Ayresshire	540	375	150
Guernsey	480	335	140
Brown Swiss	600	415	170
Illawarra/ Aussie Red	550	375	150

Stock sales

A new 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 8, 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 baseline 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 8, 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.

	Milking Cows	Heifers >1 yr age
Livestock numbers	450	120
Liveweight	500	350
Daily liveweight gain		0.7
Number of stock sold each year	115	10
Liveweight at point of sale	550	425

Heifers <1 yr age	Mature bulls	Other stock < 1 yr age
125	8	100
150	600	200
0.7		1
0	4	100
0	600	400

Other stock > 1 yr age	Calves	Calves sold post-weaning
0		head
0		kg/head
0		kg/day
0	215	head
0	105	kg/head
	132	t LW/annum

Figure 8. The livestock numbers section for the “Baseline farm” sheet (note this section of data entry has been broken down into three images to make it easier to read the text).

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 9, with 4.3 typed in the white 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 white 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 9). Check to ensure the average milk production per day is reasonable. If not, check data entry and amend as required.

Select option for milk production	litres per herd per annum
Average annual milk fat (%)	4.3 %
Average lactation length (days)	300 days

Amount of milk produced	3,000,000	litres of milk per herd per annum
Average annual milk protein	3.2	%
Average milk production	22.2	litres per cow per day

Figure 9. Annual milk production section for the “Baseline farm” sheet (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 CH₄ and N₂O 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 10 below). This action will lead you to a new sheet within ADCC, where there is a table of feeds, and their corresponding feed quality ranges to use as estimates. The feed quality sheet can also help you convert megajoules of energy (ME; MJ/kg dry matter) to DMD%. Additionally, the feed quality sheet 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 10. 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 10).

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 CH₄ emissions) are estimated using other data, such as milk production and liveweights.

Milker average annual diet intakes and 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			
By-products			
Other	1.0	70.0	22.0
Total (kg DM/day) or average (%)	17.0	75.8	18.6

Figure 10. Milker average intakes and feed quality section for the “Baseline farm” system.

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 11), 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 11. Recommended DMD and CP % for all other stock

Step five: Fertiliser inputs

Fertiliser inputs are used to estimate N₂O emissions from the application of fertilisers, CO₂ 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 11). 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 12). The white cells for the *Area of pastures and crops fertilised* questions will all turn to purple to indicate they are not required.

In this example, we applied 55 t N/annum to pastures across the whole farm (remember to include your outblock/runoff block), 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 CO₂ released when applied to pastures and crops. In Figure 12, 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 CO₂ when applied to pastures and crops as atmospheric CO₂ was not incorporated into these fertilisers when manufactured.

The screenshot shows a form titled 'tonnes of element per annum'. A button labeled 'Click here to work out fertiliser rates' is circled in red. The form contains the following fields:

Rate of N fert.				
Amount of N applied to pastures	55	t per annum		
Amount of N applied to crops		t per annum		
Percentage of N fertiliser that is urea	95	%		
	Rate of P fert.	Rate of K fert.	Rate of S fert.	Rate of Lime/dolomite
Rate of P K S & Lime/dolomite to pastures	10	3	3	150
	t per annum			
Rate of P K S & Lime/dolomite to crops		t per annum		

Figure 12. Fertiliser inputs when selecting the tonnes of element per annum option.

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 13). The *Area of pastures and crops fertilised* cells while transition from purple to white 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 13 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.

The 'Fertilisers' section of the form asks 'How do you which to enter the fertiliser rates?'. It contains the following fields:

	Area of N fertiliser	
Area of pastures fertilised with N	250	ha
Area of crops fertilised with N		ha
	Area of P K S & Lime fertiliser	
Area of pastures fertilised with P K S & Lime	125	ha
Area of crops fertilised with P K S & Lime		ha

The screenshot shows a form titled 'kg of element per ha per annum'. A button labeled 'Click here to work out fertiliser rates' is present. The form contains the following fields:

Rate of N fert.				
Amount of N applied to pastures	250	kg per ha per annum		
Amount of N applied to crops		kg per ha per annum		
Percentage of N fertiliser that is urea	95	%		
	Rate of P fert.	Rate of K fert.	Rate of S fert.	Rate of Lime/dolomite
Rate of P K S & Lime/dolomite to pastures	80	24	24	1200
	kg per ha per annum			
Rate of P K S & Lime/dolomite to crops		kg per ha per annum		

Figure 13. 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 10 tonnes of lime per hectare across 200 hectares every 6th year. Total lime purchased is 2,000 tonnes so if you enter 2,000 tonnes, all the emissions associated with production and application to land will be counted in this year’s estimate, equivalent to 930 t CO₂e. A better method would be to divide the total amount purchased by the number of years between applications, so 2,000 tonnes divided 6 years = 333.3 tonnes of lime per annum, equivalent to 155 t CO₂e/annum. If this option is elected, you must then report this same rate of lime for the subsequent 5 years otherwise you are misrepresenting the emissions associated with lime applications. If, however, you apply 10 tonnes of lime/ha to 1/6th of the land area (33.3ha in this example), the total amount of lime remains 333.3 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 14).

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.

Energy consumption	
Annual Electricity Use (kWh)	175,000 kWh
Annual Diesel/ unleaded petrol (litres)	15,000 litres
Where does your electricity come from?	State Grid
What % of electricity is from renewables?	10 %

Figure 14. Electricity consumption, source (State Grid) and percentage from renewable sources (10%), along with fuel consumption (note this section of data entry has been broken down into two images to make it easier to read the text).

Diesel consumption

Enter the amount of diesel/unleaded petrol consumed per annum across the farm. 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 15).

An example may be that a farmer used a contractor to fertilise 100ha, 3 times per year, so $100\text{ha} \times 3 \text{ times/annum} \times 3 \text{ litres of diesel/ha} = 900 \text{ litres of diesel}$. Another example is that 50 hectares was cut, tedded, raked, baled, and wrapped as silage. Thus, $50\text{ha} \times 9 \text{ litres for mowing}$, $50\text{ha} \times 3 \text{ litres for tedding}$, $50\text{ha} \times 3 \text{ litres for raking}$, $50\text{ha} \times 16 \text{ litres for baling}$ and $50\text{ha} \times 9 \text{ litres for silage wrapping} = 2,000 \text{ litres of diesel}$. 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.

How any litres of diesel and unleaded petrol did the farm use last year?

Remember to consider the fuel that would have been consumed if you use contractors to undertake some/ all of your field work (e.g. silage making, fertiliser spreading, direct drilling new pasture seed etc).

Approximate consumption figures are:
Fertilising/ chemical spraying/ rolling/ raking- 3 litres/ha
Sowing/ mowing/ wrapping silage- 9 litres/ha
Baling/ harvesting/ discing- 16 litres/ha
Ploughing/ tillage- 22 litres/ha

So if you were making silage from a 1ha paddock, with the grass cut, tedded and raked before baling and wrapping, it is likely that 40 litres per hectare may have been consumed (i.e. 9 litres/ha for cutting, 3 litres/ha for tedding, 3 litres/ha for raking, 16 litres/ha for baling and 9 litres/ha for wrapping).

Figure 15. 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 businesses, a dairy farm and a cropping farm and the emissions for the cropping farm is included in the dairy emissions (e.g. fuel and fertilisers), this does not constitute purchased supplementary feed, as the emissions have already been included. 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 16). Suppose you purchased a large amount of supplementary feed towards the end of the assessment year. In this case, you could consider transferring this purchase to the following year of assessment to better reflect when that purchased feed was consumed on farm.

So that the GHG emissions associated with these purchased supplements, you now need to determine the percentage allocated to dairy. This is the milking cows, dry cows, bulls and all replacement heifers. We have assumed that 100% of the grain/concentrate supplements are fed to either the milkers or the replacement heifers, accepting that some hay and/or grain may be fed to unweaned calves, both heifers and bulls, to begin rumen development. In this example below, all 200 t DM of the purchased pasture is allocated to the dairy enterprise.

Another example might be you purchase 200 t DM of pasture silage, of which 80% goes to the milkers and dry cows, and the balance 40 t DM is fed to the steers. You also purchased another 50 t DM of cereal hay, with 100% allocated to the beef enterprise as you are fattening up some steers. In this example, $200 \times 80\% = 160$ tonnes goes to the dairy enterprise and the balance 90 t DM (i.e. 40 t DM silage + 50 t DM hay) goes to the beef enterprise, thus 160 t DM to dairy/ 250 t DM total = 64% is allocated to dairy. This whole value is entered into the Proportion of purchased fodder allocated to dairy (%) white cell.

Purchased supplementary feed		
Pasture or cereal hay (t DM)	<input type="text" value="200"/>	t DM
Pasture silage (t DM)	<input type="text"/>	t DM
Grain/ concentrates (t DM)	<input type="text" value="700"/>	t DM

Lucerne/ legume hay (t DM)	<input type="text"/>	t DM	Proportion of purchased fodder allocated to dairy (%)
Cereal/ maize silage (t DM)	<input type="text"/>	t DM	<input type="text" value="100"/>
By-products (t DM)	<input type="text" value="180"/>	t DM	

Figure 16. Screenshot of a component of the purchased supplementary feed inputs. This image shows that all purchased fodder, so the 200 tonnes of pasture/cereal hay was fed to the dairy enterprise as opposed to a proportion going to the beef enterprise (note this 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 sheet, 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 sheet (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 17 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 sheet 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 sheet, 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 sheet will result in either errors or zero carbon sequestration results.

Carbon sequestration in tree plantations	
How are you estimating this?	Based on data entered here
Choose your region of Australia	South West VIC
Choose the type of trees planted	Mixed species (Environmental Plantings)

Area of trees (ha)	10	Age of Trees	15
Amount of carbon sequestered using other tools			t CO ₂ e/ha.annum

Figure 17. 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, a new cell will appear asking for the amount of carbon sequestered (t CO₂e/ha) using other tools (Figure 18). For instance, you may use the FullCAM model (<https://www.industry.gov.au/data-and-publications/full-carbon-accounting-model-fullcam>) or the LOOC-C online tool (<https://looc-c.farm/>) to determine the likely amount of CO₂e sequestered on your farm with your tree species. In that case, you will only enter the amount of CO₂ sequestered, and the area of trees planted; all other cells can remain blank (e.g. age of trees in Figure 18). In the below example, LOOC-C estimated that the 15 ha of trees sequestered 6.5 t CO₂e/ha.annum. **NOTE** other calculators may report the change in carbon as tonnes of carbon as opposed to CO₂e (e.g. FullCAM). To convert from tonnes of carbon to tonnes of CO₂e, multiply the tonnes of carbon by 3.67 (e.g. 5 t C/ha.annum = 18.35 t CO₂e/ha.annum).

Area of trees (ha)	15	Age of Trees	
Enter amount of carbon sequestered if using other tools		6.5	t CO ₂ e/ha.annum

Figure 18. 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.

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 19).

Make sure you enter from the top and work your way down the sheet 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 Baseline 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 Baseline tab/ 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, we had 2.5ha of five year old Mixed species sequestering 2.46 t CO₂e/ha.annum (estimated within ADCC) and 5.8ha of eight year old Tasmanian Blue Gums sequestering 2.0 t CO₂e/ha.annum (estimated within ADCC). The average sequestration rate across both areas of land was 2.33 t CO₂e/ha, resulting in a total sequestration of 18.92 t CO₂e/annum. It is this value that you copy back into the Baseline tab.

Area 1	State Region Species of Tree Area of Trees Age of Trees	VIC South West VIC Mixed species (Environmental Plantings) 2.5 ha 5 years
Area 2	State Region Species of Tree Area of Trees Age of Trees	VIC South West VIC Tasmanian Blue Gum 5.8 ha 8 years
Area 3	State Region Species of Tree Area of Trees Age of Trees	 ha years
Area 4	State Region Species of Tree Area of Trees Age of Trees	 ha years
Tonnes sequestered	Area 1 Area 2 Area 3 Area 4 Average Total	2.46 t CO ₂ e/ha 2.20 t CO ₂ e/ha t CO ₂ e/ha t CO ₂ e/ha 2.33 t CO ₂ e/ha 18.92 t CO ₂ e/annum

Figure 19. Screenshot of the ability to explore up to four areas of farm in terms of vegetation carbon sequestration.

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 CO₂e/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 CO₂e. Enter 100 ha in the Area of trees cell and 0.734 in the t CO₂e/ha.annum cell, and ADCC will estimate that the soil sequestered 73.4 t CO₂e/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 handled 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 CH₄ 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 20). Most manure is allocated to pastures, then the lagoon system, with small 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.

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 handled (Figure 20). This is done by selecting '*User-defined factors and fractions*' from the drop-down list. Then you are required to answer a series of questions to determine how long the milking herd is at the dairy, how the dairy manure is handled, how long the milking herd is on a feedlot, and how the feedlot manure is handled. 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, you could consider it as what are the two ways in which the manure is handled? 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/ in a compost barn structure where the bedding and manure is frequently aerated and thus a similar rate of loss of emissions as the scrapped & 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, 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 scrapped & 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 mechanical separation of the manure as it is flushed to the lagoon system, this material is also considered of scrapped & 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.

However, 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/scrapped & 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. If you selected some form of mechanical solids separation of the lagoon-destined manure, 20% of this manure will also be allocated to solid storage. In this example, the proportion of manure to solid storage would increase to 78.1%, the lagoon waste would remain on 21.9%, with 0% of manure going onto pastures.

In some circumstances, heifers might also be retained off paddocks, such as in TMR farms. In these instances, ADCC also needs to estimate the time these animals are on hard surfaces where their manure is collected. ADCC uses this same data for steers and bulls if this second '*User-defined factors and fractions*' option is selected. 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.

Figure 20 is an example of entering data to determine how the manure is handled 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. ADCC assumes all the manure is flushed to a pond/lagoon system, unless the user enters the percentage of waste flushed and then drained to the paddock and/or spread daily from a sump/dispersal system. In this example, we also assumed there was some form of pre-treatment (selected from the appropriate drop-down list), with a solids-trap in place to collect some of the solids (default is 20% collected). The milkers then spent 2 hours per day for 300 days per annum on a feedlot, where the manure was scrapped and stockpiled. ADCC has calculated that 11% of the milkers' manure is handled via a lagoon system (manure from the dairy), and 9.6% of their manure is handled as solid storage (solids trapped from the dairy before entering the lagoon plus the manure from the feedlot). The balance of the manure is deposited on pastures during grazing. In this example, all other stock remains grazing year-round, so 100% was allocated to pastures.

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 total farm GHG emissions.

Manure management

Choose which option you are using to estimate how animal waste is handled Volatile solids kg VS/head.day for the milking cows

% waste to each manure management system	Anaerobic lagoon	Sump dispersal	Drain to paddock	Solid storage	Pasture
Milkers	11.0	0.0	0.0	9.6	79.5
All other stock	0.0	0.0	0.0	0.0	100.0

Only answer the following questions if you wish to enter your own farm management practices to estimate the percentage of waste to each of the abovementioned manure management systems. In addition, you must have selected the User-defined factors and fractions option in the drop-down list at the beginning of this section otherwise the results will still reflect the default state-based fractions and factors.

Milkers

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

Percentage of waste that is flushed and then drains to the paddock with no treatment/ removal of solids %

Percentage of waste that is flushed and then spread daily from a sump/dispersal system (with or without removal of solids) %

Balance assumed to be flushed and then enter a pond/lagoon system %

Do you pre-treat the waste prior to spreading daily or entering the lagoon (e.g. weeping wall, solids trap, mechanical separator to remove a fraction of the solid)

Number of hours per day and days per annum a milker spend on a feedpad or loafing area or are housed (TMR farm)

Select the option which best describes how the majority of this waste from the feedpad or loafing area is best handled Integrated MCF %

Heifers

Number of hours per day and days per annum the heifers spend in yards or are housed where the waste is deposited

Select the option which best describes how this waste from the feedpad or loafing area is best handled Integrated MCF %

Figure 20. 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. Baseline 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 12), estimated trees on farm based on data entered here (Figure 17), and used the default state-based factors and fractions for manure management. Total GHG emissions were 3,588 t CO₂e. However, as there were trees on farm sequestering 29 t CO₂e/annum (shown as -29 t CO₂e/annum to reflect carbon sequestration), the resultant net emissions were 3,558 t CO₂e/annum. Approx. 86% of net GHG emissions were allocated to milk production, with the balance 14% attributed to meat production. Milk EI was estimated at 0.96 kg CO₂e/kg FPCM or 13.58kg CO₂e/kg MS, while meat EI was estimated at 3.80 kg CO₂e/kg liveweight (Figure 21). Due to the difficulty of showing the full results section, we have broken this table down into subsections, shown in Figures 22 to 26.

Results for baseline farm system										
		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 ₂ e/annum)	% of total GHG (exc. C sequestration in trees)
Methane (Scope 1):	Enteric fermentation	1,648	182	89	15	91	0		2,025	56%
	Manure management	322	4	2	0	2	0		330	9%
Nitrous oxide (Scope 1):	Direct from dung & urine voided onto pastures	97	16	7	1	7	0		128	4%
	Direct from manure (storage & spread)	34	0	0	0	0	0		34	1%
	Indirect N waste	101	14	6	1	6	0		128	4%
	Direct N fertiliser							89	89	2%
Carbon dioxide:	Indirect N fertiliser							71	71	2%
	Electricity (Scope 2)								161	4%
	Electricity (Scope 3)								16	0%
	Diesel and unleaded petrol (Scope 1)								41	1%
	Diesel and unleaded petrol (Scope 3)								2	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		2,203	215	104	18	106	0	160	3,588	t CO₂e/annum
% of total GHG emissions (before carbon sequestration is taken into account)		61%	6%	3%	0%	3%	0%	4%		
Carbon sequestration	Tree plantings, with negative figures representing amount of carbon sequestered								-29	t CO₂e/annum
Net GHG emissions									3,558	t CO₂e/annum

Figure 21. Screenshot illustrating the results for the whole farm (segmented in 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 22 shows the breakdown of emission for the milking herd, mostly CH₄, with enteric fermentation at 1,648 t CO₂e, and manure management at 323 t CO₂e. The milking herd was responsible for 2,203 t CO₂e, equivalent to 61% of total farm GHG emissions. Emissions for the Heifers > 1 yr age were significantly lower, at 215 t CO₂e/annum, representing 6% of total farm GHG emissions.

Results for baseline farm system

		Milking Cows	Heifers >1 yr age
Methane (Scope 1):	Enteric fermentation	1,648	182
	Manure management	322	4
Nitrous oxide (Scope 1):	Direct from dung & urine voided onto pastures	97	16
	Direct from manure (storage & spread)	34	0
	Indirect N waste	101	14
	Direct N fertiliser		
Carbon dioxide:	Indirect N fertiliser		
	Electricity (Scope 2)		
	Electricity (Scope 3)		
	Diesel and unleaded petrol (Scope 1)		
	Diesel and unleaded petrol (Scope 3)		
Pre-farm gate embedded (Scope 3)	Urea and Lime/dolomite (Scope 1)		
	Grain/ concentrates		
	Forages		
	Fertilisers		
Total GHG emissions		2,203	215
% of total GHG emissions (before carbon sequestration is taken into account)		61%	6%

Figure 22. 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, CH₄ from enteric fermentation across the whole herd totalled 2,026 t CO₂e, equivalent to 56% of total farm GHG emissions (Figure 23). The second largest source was CH₄ from manure management, mainly associated with the manure while in effluent ponds, at 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 0 and 4% of total GHG emissions (Figure 23). Here we can also see that trees were able to sequester 29 t CO₂e/annum (shown as a negative value), decreasing net farm GHG emissions to 3,559 t CO₂e/annum.

Results for baseline farm system

		Total GHG (tonnes CO ₂ e/annum)	% of total GHG (exc. C sequestration in trees)
Methane (Scope 1):	Enteric fermentation	2,026	56%
	Manure management	331	9%
Nitrous oxide (Scope 1):	Direct from dung & urine voided onto pastures	128	4%
	Direct from manure (storage & spread)	34	1%
	Indirect N waste	128	4%
	Direct N fertiliser	89	2%
	Indirect N fertiliser	71	2%
Carbon dioxide:	Electricity (Scope 2)	161	4%
	Electricity (Scope 3)	16	0%
	Diesel and unleaded petrol (Scope 1)	41	1%
	Diesel and unleaded petrol (Scope 3)	2	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		3,588	t CO₂e/annum
% of total GHG emissions (before carbon sequestration is taken into account)			
Carbon sequestration	Tree plantings, with negative figures representing	-29	t CO₂e/annum
Net GHG emissions		3,559	t CO₂e/annum

Figure 23. Screenshot illustrating the total farm GHG emissions and percentage of total farm greenhouse gas emissions for each source (note some 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 approx. 86% of GHG emissions are attributed to milk production, using an adapted method based on the that described by IDF (2022). Therefore, EI was 0.96 kg CO₂e/kg FPCM or 13.58 kg CO₂e/kg milk, while meat EI was 3.80 kg CO₂e/kg liveweight (Figure 24). 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, 0.96 kg CO₂e/kg FPCM divided by 86% allocated to milk equals an EI of ~ 1.12 kg CO₂e/kg FPCM.

	kg CO ₂ e/kg FPCM (your farm)
GHG emissions intensity (kg CO₂e/kg fat and protein corrected milk (FPCM))	0.96
GHG emissions intensity (kg CO₂e/kg milksolids)	13.58
GHG emissions intensity (kg CO₂e/kg liveweight)	3.80
Proportion of net emissions allocated to milk	86%
Proportion of net emissions allocated to meat	14%

Figure 24. Screenshot illustrating the emissions intensity of milk and meat production when a proportion of emissions are allocated to meat (note some columns 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 25). In the example below, the graphs have been presented vertically here due to the size of the graphs. Around 56% of the farm's net GHG emissions was enteric CH₄, compared to around 58% for the typical average farm (dark blue columns). In contrast, urea and lime emissions (lime green columns) are double for the farm examined here, at 4% compared to 2% for the typical farm (Figure 25; see Appendix 4 for the typical/industry average values).

If EI for the farm is outside an expected range of between 0.6 and 1.2 kg CO₂e/kg FPCM or between 8 and 18 kg CO₂e/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. 1,775 datasets from 2015-16 to 2020-21 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 or against the Australia-wide average. We have also included a comparison of the farm system, based on the level of grain feeding. Users can select either low grain feeding (< 1 t DM/cow.lactation), medium grain feeding (1-2 t DM/cow.lactation) or high grain feeding (> 2 t DM/cow.lactation). These numbers are also presented in Appendix 4.

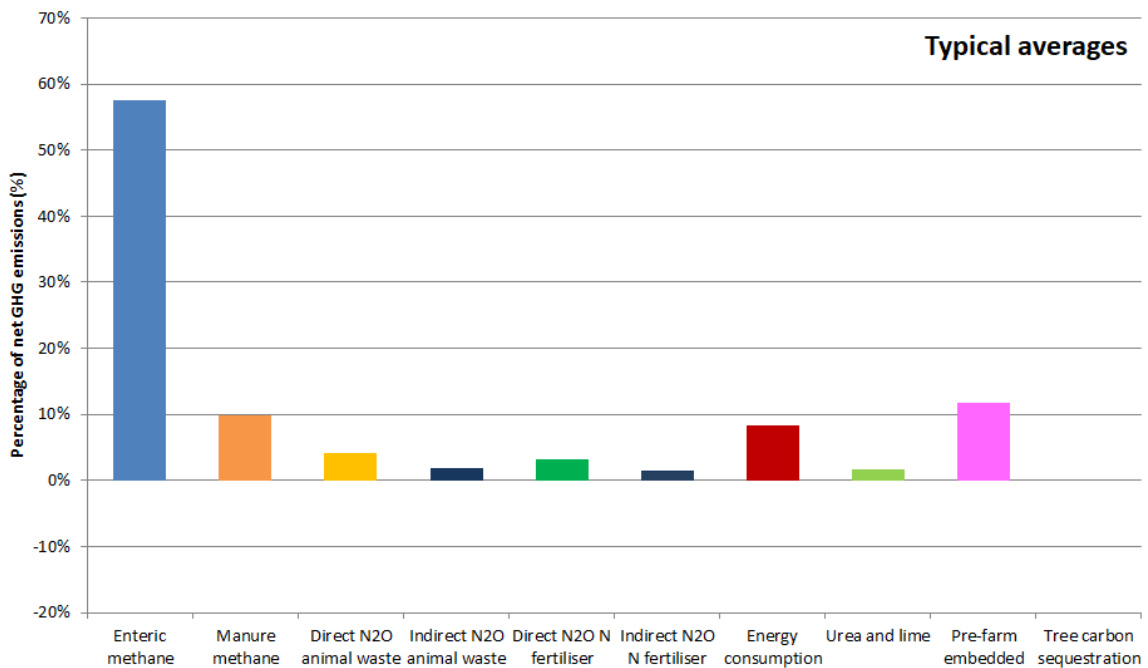
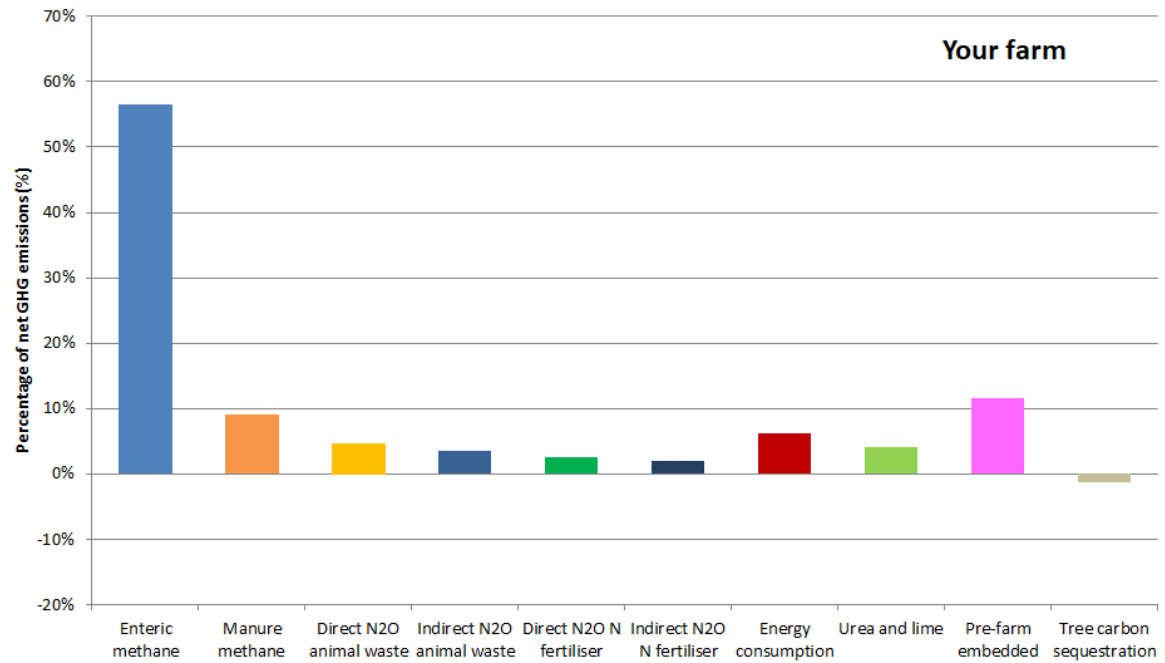


Figure 25. Screenshot of the percentage of the total greenhouse gas emissions and carbon sequestered in trees for the farm being assessed (top image) compared to a typical average (bottom image).

Figure 26 illustrates a new addition to the calculator with version 5.2, in that we also now present the typical average emissions intensity for each source of emissions, along with the total emissions intensities (kg CO₂e/ kg FPCM, kg CO₂e/ kg MS and kg CO₂e/kg LW) and proportion of emissions attributed to milk and meat production. These values are also included in Appendix 4. In this example, the emissions intensity for most sources is very similar to the industry comparison- south west Victoria in this example. A couple of differences are in terms of Urea and Lime/dolomite being double that of the industry average, while the baseline's Diesel and unleaded petrol emissions intensity is half that of the industry average. The baseline farm had more meat production than the industry average, with 14% of emissions allocated to meat, resulting in a lower meat emissions intensity of 3.8 kg CO₂e/kg LW compared to 4.43 kg CO₂e/kg LW for the industry average. Overall, the baseline farm is quite similar to the industry average for the region.

kg CO ₂ e/kg FPCM (your farm)		kg CO ₂ e/kg FPCM (industry comparison)	
0.55	✓	0.55	Enteric fermentation
0.09	✓	0.09	Manure management
0.03	✓	0.03	Direct from dung & urine voided onto pastures
0.01	✓	0.01	Direct from manure (storage & spread)
0.03	✓	0.02	Indirect N waste
0.02	✓	0.03	Direct N fertiliser
0.02	✓	0.02	Indirect N fertiliser
0.05	✓	0.05	Electricity (Scope 2 &3)
0.01	✓	0.02	Diesel and unleaded petrol (Scope 1 & 3)
0.04	✓	0.02	Urea and Lime/dolomite
0.04	✓	0.05	Grain/ concentrates
0.01	✓	0.01	Forages
0.07	✓	0.06	Fertilisers
0.96	✓	0.95	kg CO ₂ e/kg FPCM (post carbon sequestration)
13.58	✓	11.68	kg CO ₂ e/kg milksolids (post-carbon sequestration)
3.80	✓	4.43	kg CO ₂ e/kg liveweight meat (post-carbon sequestration)
86%	✓	88%	Proportion of emissions allocated to milk
14%	✓	12%	Proportion of emissions allocated to meat

Figure 26. Screenshot showing the comparison of emission intensities for the baseline farm compared to the industry comparison, which is south-west Victoria in this example.

5.7. Previous methodology comparison

Over time, as new knowledge from scientific research emerges, the NNGI methodology is updated. Examples of this have been changes to the Australian enteric CH₄ equation or changes to global GWPs for CH₄ and N₂O. The Australian NNGI methodology was developed in 1990, and since then there has been two major updates, in 2017 (ADCC version 4), and more recently in 2022 (current ADCC version 5). Within ADCC, we have retained these two older methodologies, facilitating users to compare the same farm input data across all three NNGI methodologies. By entering data into the “Baseline farm” sheet, this populates and estimates the 1990 and 2017 methodology comparisons.

For the example farm used predominantly throughout this manual, and presented in the previous section, after implementing brown coal as the source of electricity, considering the amount of carbon sequestered in trees, and using the new method of estimating carbon sequestration in trees, net GHG emissions was 3,216 t CO₂e/annum with the 1990 methodology, increasing to 3,266 t CO₂e/annum with the 2017 methodology, thus both methodologies are lower than the current results of 3,559 t CO₂e/annum with the 2022 methodology. Emissions intensity followed a similar pattern as net farm emissions were divided by the same amount of milk production.

The biggest contributor to the rise in net GHG emissions over time has been the increase in GWP of CH₄. In 1990, the NNGI 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 N₂O has declined from 310 to 298, and now to 265 (Myhre *et al.* 2013). Inclusion of CO₂ 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 CH₄, 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) 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.

5.8. Importing a DairyBase farm system file into ADCC

A new feature of ADCC version 5.2 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 7). In the top right corner of the Baseline farm tab, there is an Import from DairyBase button (Figure 27), 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 Appendices 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 27. Screenshot of the top right corner of the Baseline farm tab showing the button to clear input cells and to import a DairyBase farm file along with hyperlinks to the Introduction sheet 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 (< 0.5%) due to how each calculator determines aspects such as stock numbers. 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, similar to that shown in Figure 28, 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, in this case electricity data entry. You may need to enter missing data.

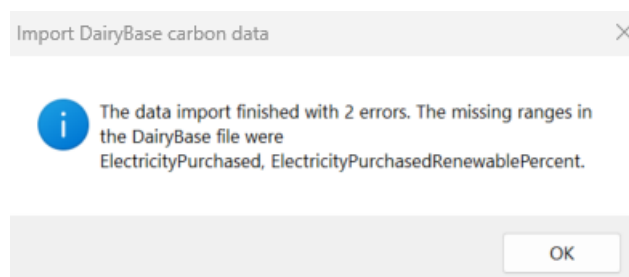


Figure 28. Example of an error message when importing an older DairyBase farm file.

A new feature we have also added into version 5.2 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 corner of the tab.

6. Benchmarking of DairyBase results

Benchmarking your farm data can be a good 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 (DFMP) for the years 2006/07 to 2020/21 inclusive. While DairyBase contains over 3,000 DFMP datasets, this review was restricted to the 1,775 datasets which contained a complete list of realistic input data. For example, datasets with missing electricity and/or diesel consumption data were excluded from the analysis (e.g. some of the earlier years for Tasmania). Likewise, datasets with N fertiliser inputs which appeared to be total tonnes, as opposed to kg N/ha, were also excluded. 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 5.3). Therefore, estimating carbon sequestration in trees for these 1,775 datasets was impossible. Hence, all results presented in this section 6 do not contain any potential reduction in net GHG emissions with sequestering carbon in tree plantings.

Figure 29 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. As shown in Figure 29, there was a rapid decline in the number of datasets in 2016/17, due to ~ 80 datasets missing electricity and fuel consumption data, thus failing to meet the criteria for this review.

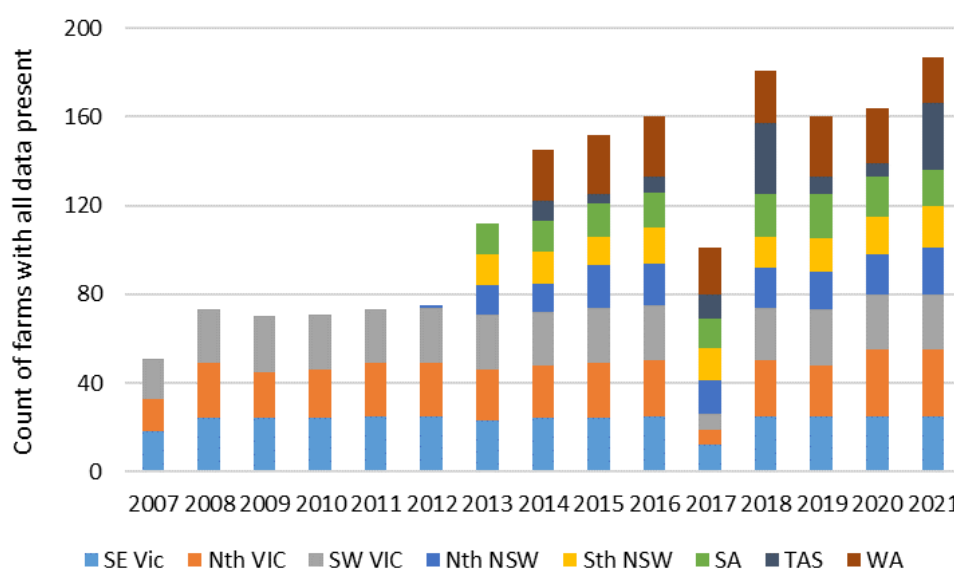


Figure 29. Number of Dairy Farm Monitor Project datasets for each year from each dairy region where all the data was included in DairyBase. Note the year reflects the second half of the financial year, so 2007 reflects 2006/07. No QLD data was assessed due to missing electricity and diesel consumption data.

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 0.92, with a residual 'a' value of 13 (Figure 30). The co-efficient of determination (R^2 ; where an R^2 of 1 indicates the regression prediction perfectly fits the data) was 0.97, thus indicating that this regression equation is an excellent predictor of net GHG emissions from milk production (Figure 27). Therefore, we can have high confidence that if a farm's milk production was 5,000 t FPCM/annum, their approx. GHG emissions could be estimated as $5,000 \times 0.92 + 13 = 4,613$ t CO₂e/annum.

However, the orange dot farm datasets in Figure 30 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 mean. Orange dots that sit above the blue regression line indicate their GHG emissions estimated in DairyBase is greater than predicted from annual milk production. This could potentially indicate 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 30).

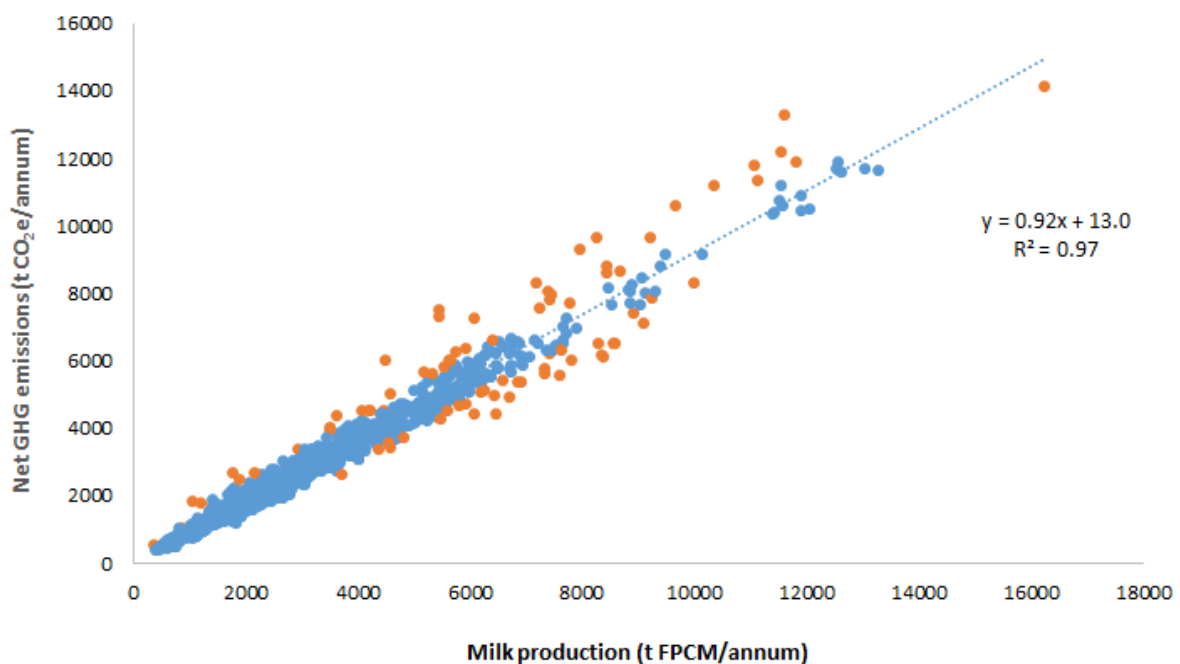


Figure 30. Linear regression relationship between milk production (t FPCM/annum) and net GHG emissions (t CO₂e/annum). The orange dots indicate farm datasets with a standard residual > 2 , indicative of outlier results relative to the linear regression relationship.

The EI of milk production, prior to taking an allocation of meat production into consideration, is presented in Table 2. The overall mean for Australia, across the 13 years of data, was 1.07 kg CO₂e/kg FPCM. This is a 4.5% increase in results based on the previous NGGI methodology, at 1.03 kg CO₂e/kg FPCM. The main reason for the increase was most likely due to an increase in GWP of CH₄ (see section 5.7 for explanations of the changes that have occurred since the update of the calculator with the newest NGGI methodology).

Table 2. Mean regional and national emissions intensity (kg CO₂e/kg FPCM) when allocating all GHG emissions to milk production. Old NGGI refers to the 2017 methodology results. FY 2007 reflects the 2006-07 financial year.

Year	SE Vic	Nth Vic	SW VIC	Nth NSW	Sth NSW	SA	TAS	WA	Aus wide	No. farms	Old NGGI
FY 2007	1.16	1.18	1.04						1.12	51	1.09
FY 2008	1.11	1.04	1.10						1.08	73	1.04
FY 2009	1.06	1.02	1.04						1.04	70	1.00
FY 2010	1.09	1.05	1.03						1.06	71	1.02
FY 2011	1.03	1.02	1.07						1.04	73	1.00
FY 2012	1.03	1.02	1.06	1.15					1.04	75	1.01
FY 2013	1.10	1.02	1.06	1.20	1.08	1.01			1.07	112	1.03
FY 2014	1.08	1.01	1.09	1.24	1.07	1.09	1.08	1.11	1.09	145	1.05
FY 2015	1.05	1.01	1.06	1.23	1.04	0.99	1.19	1.09	1.07	152	1.03
FY 2016	1.08	1.02	1.04	1.20	1.05	1.00	1.00	1.07	1.06	160	1.03
FY 2017	1.09	1.06	1.07	1.17	1.10	0.99	1.02	1.02	1.07	101	1.01
FY 2018	1.08	1.02	1.11	1.23	1.10	1.00	1.02	1.15	1.08	181	1.01
FY 2019	1.11	1.04	1.15	1.25	1.12	1.01	0.98	1.14	1.11	160	1.05
FY 2020	1.06	0.99	1.09	1.22	1.10	1.01	0.99	1.15	1.08	164	1.02
FY 2021	1.04	0.99	1.05	1.20	1.07	0.96	0.99	1.17	1.05	187	1.00
Average	1.08	1.03	1.07	1.21	1.08	1.01	1.02	1.11	1.07	1,775	1.03
No. farms	348	343	346	154	137	145	107	195	1,775		1,149

However, as documented previously in this manual, meat production has become an increasing component of farm exports. ADCC and DairyBase allocate a proportion of GHG emissions to meat production. The legacy data within DairyBase estimated the likely number of calves born each year, assumed to be a 50:50 split between heifer and bull calves. The number of Heifers < 1 yr age was subtracted from total number of heifer calves born, with these 'non-replacement' heifer calves sold soon after birth. Similarly, all bull calves were assumed to be sold soon after birth, unless there were stock numbers included in the Other Livestock class. For example, if a farm had 400 cows milking, it was assumed there would also be ~ 400 calves. If there were 100 Heifers < 1 yr age, and 100 Other Livestock, ADCC assumed that the balance ~ 200 calves were sold soon after birth. The meat EI represents all meat sold off farm from culled cows, surplus calves, fattened livestock, and any additional Rising 1 year old replacement heifers not required to match the Rising 2 yr old replacement numbers. For example, if a farm had 120 Rising 1 year olds, and 110 Rising 2 years olds, 10 of the Rising 1 year olds were assumed to have been sold post-weaning at 150-200 kg liveweight.

After considering an allocation of net GHG emissions to meat production, the national EI of milk production reduced from 1.07 to 0.93 kg CO₂e/kg FPCM (Table 3). Unlike the results in Table 2, there is no comparative Old NGGI methodology milk EI comparison as this analysis could not be

retrospectively completed. There were minimal differences in meat EI across regions and years. However, the pattern generally trended the same way as milk EI. For example, Nth NSW had the highest milk and meat EIs. Most of the datasets had a milk EI of between 0.85 and 1.04 kg CO₂e/kg FPCM (Figure 31), while most meat EIs varied between 3.9 and 4.8 kg CO₂e/kg liveweight (Figure 32).

Table 3. Mean regional and national milk emissions intensity (kg CO₂e/kg FPCM), and meat emissions intensity (kg CO₂e/kg liveweight), when allocating a proportion of GHG emissions to meat production. FY 2007 reflects the 2006-07 financial year.

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	0.94	0.92	0.93	1.02	0.94	0.87	0.89	0.89	0.93	4.3
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

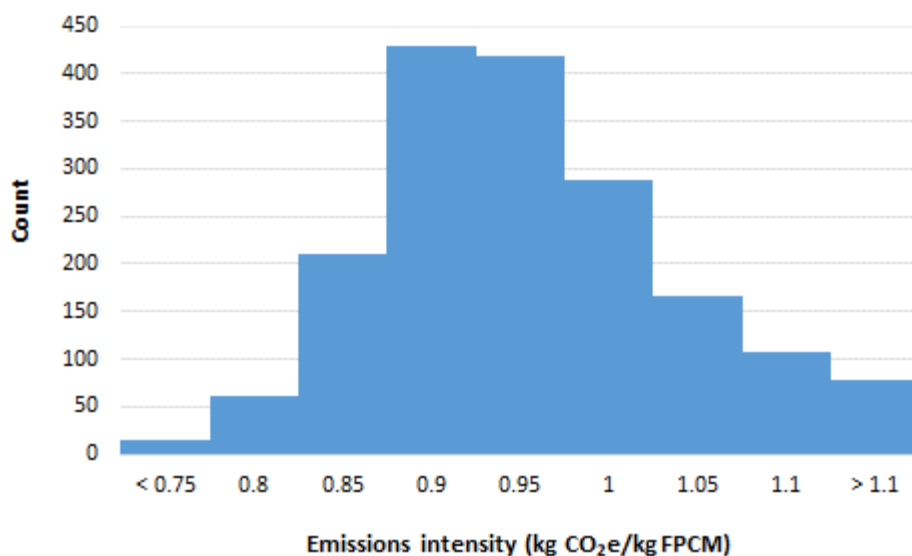


Figure 31. Frequency of emissions intensity of milk production across the 1,775 datasets once a proportion of GHG is allocated to meat production. EIs broken down into 0.05 kg CO₂e/kg FPCM increments where the number listed for each column is the upper limit such that 0.8 reflects the number of datasets with an EI between 0.75 and 0.80 kg CO₂e/kg FPCM.

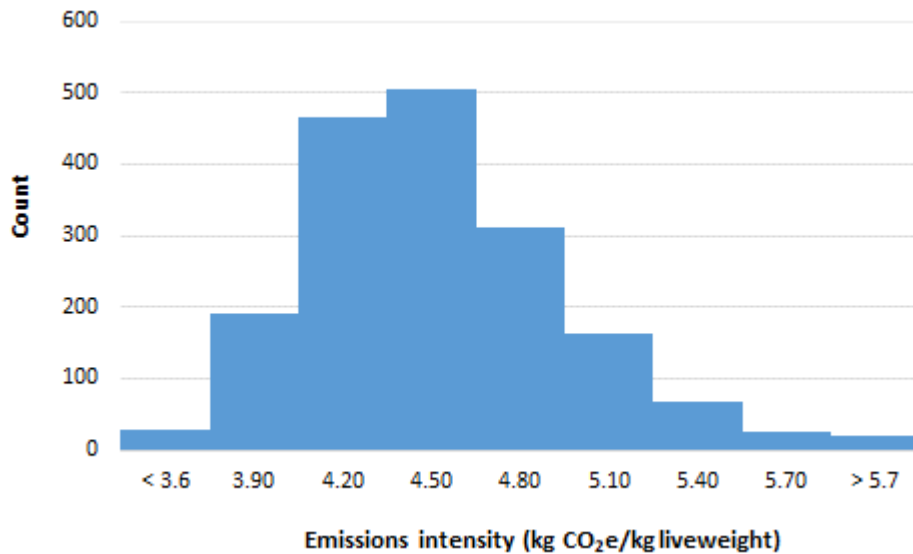


Figure 32. Frequency of emissions intensity of meat production (kg CO₂e/kg liveweight sold) across the 1,775 datasets. EIs broken down into 0.3 kg CO₂e/kg liveweight increments where the number listed for each column is the upper limit such that 3.90 reflects the number of datasets with an EI between 3.6 and 3.9 kg CO₂e/kg liveweight.

Figure 33 illustrates the proportion of emissions from each source. Enteric CH₄ was the biggest source of emissions, averaging 61% across the whole dataset, but varying between 37 and 83%. Waste CH₄ was the second highest, averaging 10% (range 5-47%). All other sources averaged < 6%, although individual farms could have greater emissions from a particular source. For example, electricity emissions were > 10% for many farm datasets, while there were several datasets > 30%. These may be data entry errors, farms with large amounts of irrigation occurring, or may reflect farms with inefficient electricity consumption in the dairy and/or irrigation infrastructure. The one farm dataset with a very high waste CH₄ source (~ 48% in Figure 34) is a total mixed ration farm where all cows and young stock are housed year round. All their waste passes through a pre-treatment mechanism, such as a weeping wall, to capture 20% of the waste in a solid storage state before the balance 80% of waste passes through the weeping wall to enter a pond/lagoon system. This farm had implemented the *User-defined factors and fractions* option to better capture their on-farm management of manure.

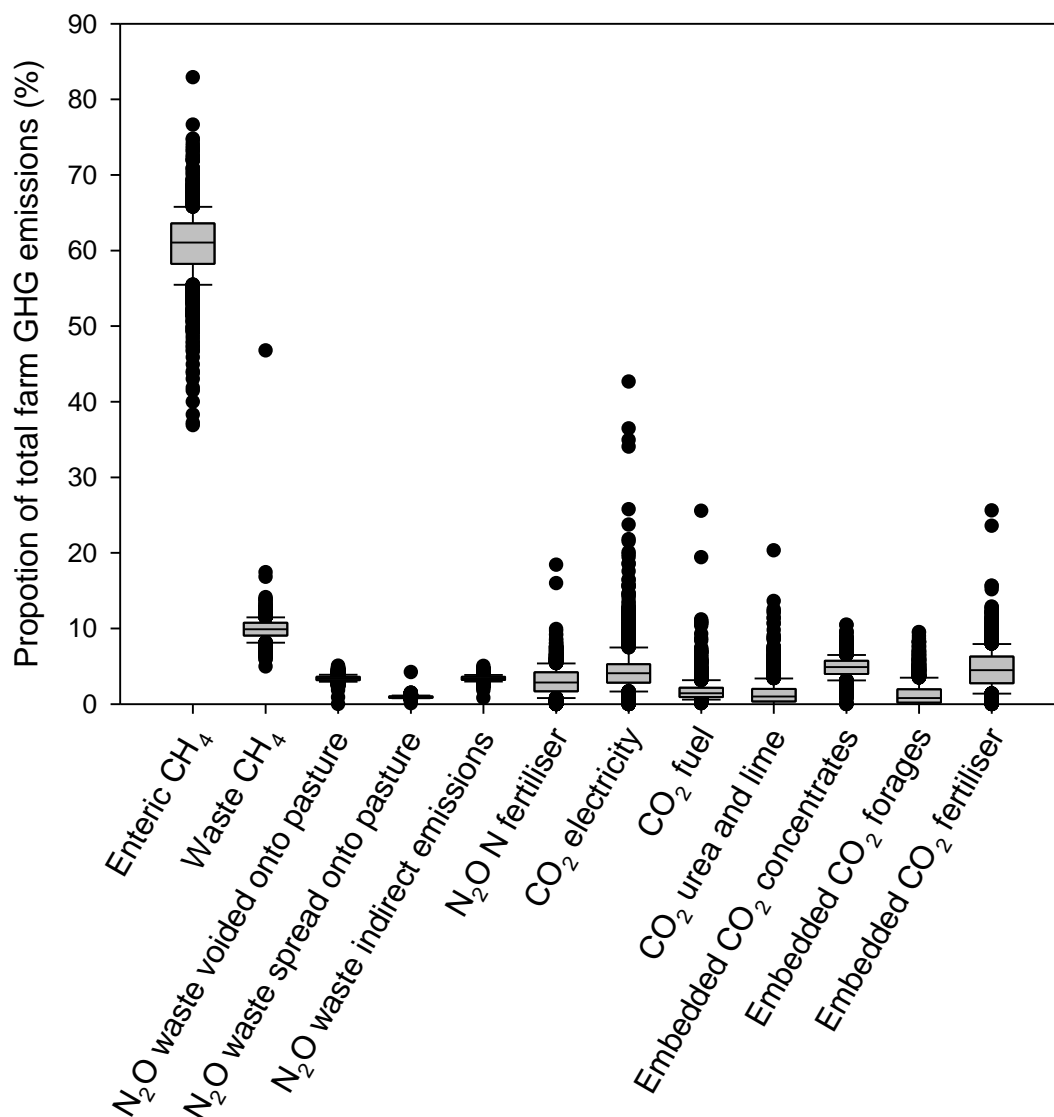


Figure 33. Proportion of GHG emissions from each source for the 1,775 farm datasets. The boxes represents the 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, dots represent outliers, and solid lines in the boxes represent the medians.

A review of the relationship between EI and milking herd size found no clear correlation (Figure 34). The red dotted line in Figure 31 represents the average EI across the dataset. The majority of farms with EIs > 1.2 kg CO₂/kg FPCM tend to be smaller herds, with the exception of a few farms milking between 800 and 1,000 cows. Similarly, EIs for herds milking > 1,500 cows also tended to have EIs higher than the overall average. 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.

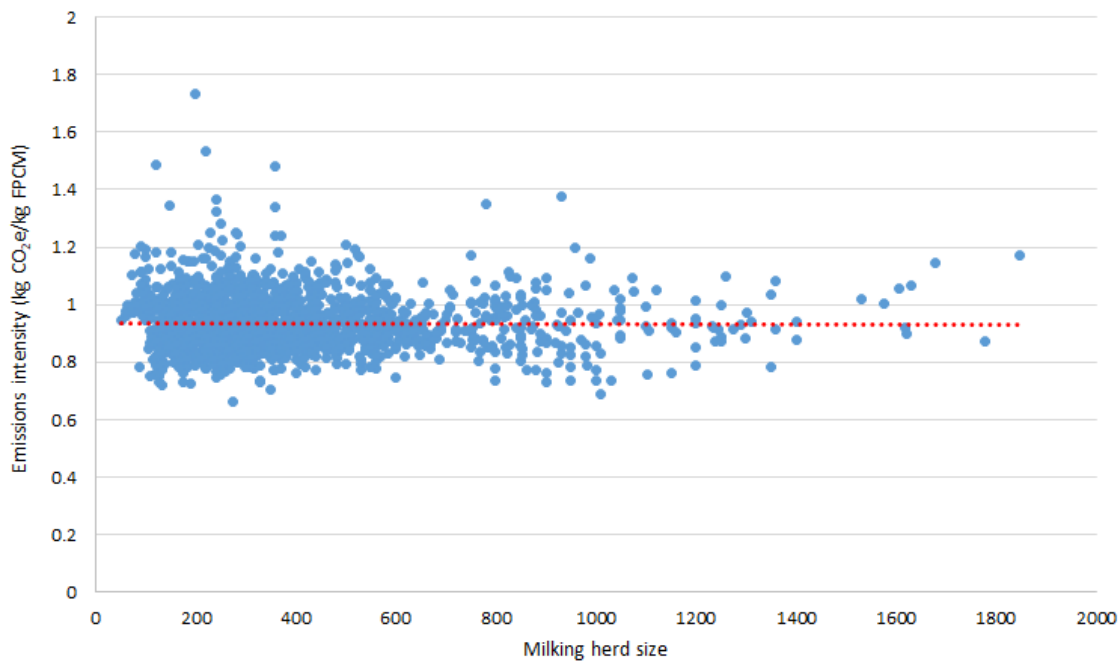


Figure 34. Relationship between milking herd size and emissions intensity. The red dotted line represents the linear regression relationship between herd size and emissions intensity.

There is a clear trend that increasing milk production per cow dilutes net GHG emissions and thus reduce the EI of milk production (Figure 35). 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 > 11,000 litres/lactation found that these appear to be total mixed ration farms given they all 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. This would underestimate waste CH₄ and N₂O emissions from stored manure, thus net farm emissions and EIs. The one exception in Figure 32 is the farm producing ~ 13,000 litres per cow and an EI of 1.33 kg CO₂e/kg FPCM. This farm's data entry reflected that all milking herd waste was stored (i.e., 80% of waste to lagoon and 20% to solid storage, indicative of a solids separation process in place on farm). If they had implemented the state-based manure factors and fractions, their EI would most likely have been close to the red regressions line in Figure 35. 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 with DFMP data collection to better reflect on-farm practices and thus net farm GHG emissions and EIs.

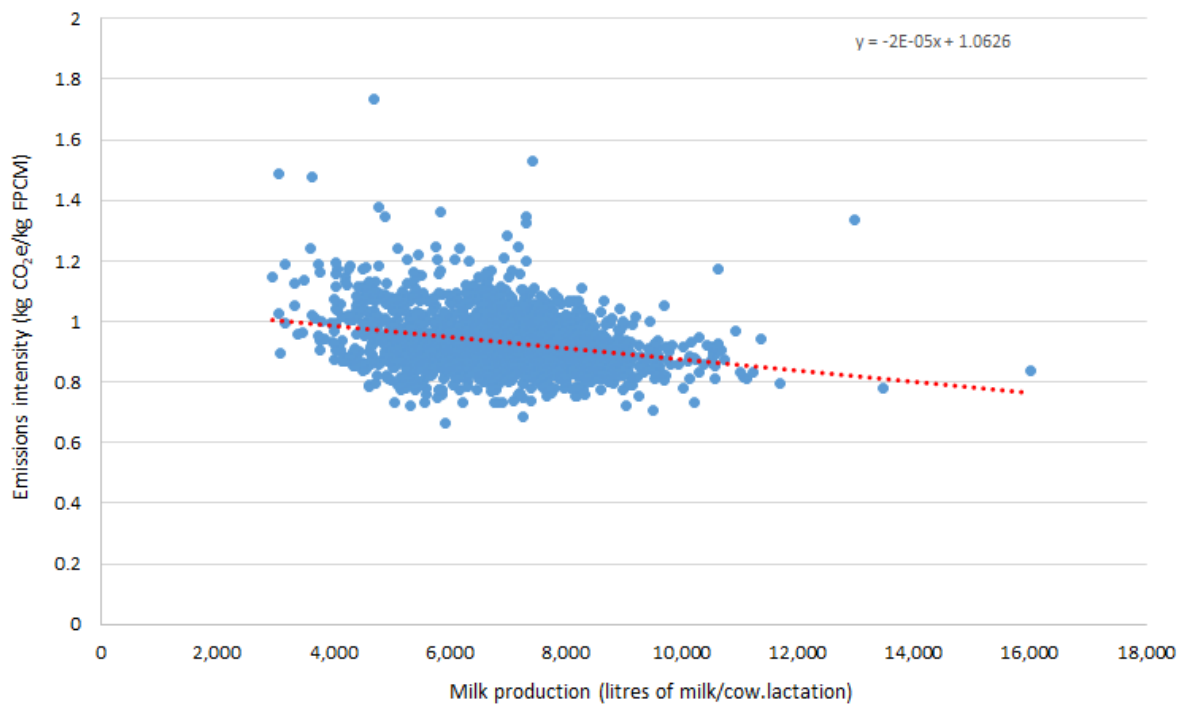


Figure 35. Relationship between milk production per cow and emissions intensity. Red dotted line represents the linear regression relationship between milk production and emissions intensity.

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 36 illustrates that as this milk efficiency ratio increases, there is a trend of reducing EIs. By targeting > 1 kg milksolids per kg of liveweight, GHG emissions can be diluted by increased milk production. The low R^2 of 0.28, 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 36 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.

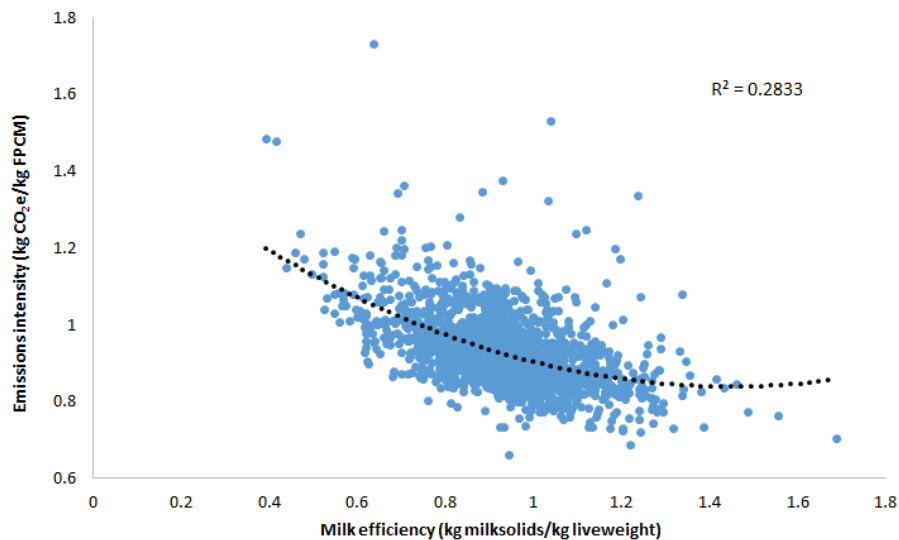


Figure 36. Relationship between milk efficiency (kg milksolids/kg liveweight of the milking cow) and milk emissions intensity (kg CO₂e/kg FPCM).

One way to improve milk production per kg of liveweight is by increasing the energy density of the diet through grain/concentrate feeding. Figure 37 illustrates the relationship between milk efficiency and EI for three grain feeding groups; low (< 1 t DM/cow.annum), medium (1-2 t DM/cow.annum), and high (> 2 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). However, the milking herd will still consume the majority of purchased grain/concentrates. The average EI was 0.98 kg CO₂e/kg FPCM for the low grain feeding group, while there was little difference between the medium and high grain feeding groups, both with a mean of EI of 0.93 kg CO₂e/kg FPCM. However, as grain feeding increased, the variation between the highest and lowest dataset EI within each grain feeding group declined (data not shown). Thus, it may be concluded that increased grain feeding reduces the variability of EI within each grain feeding group.

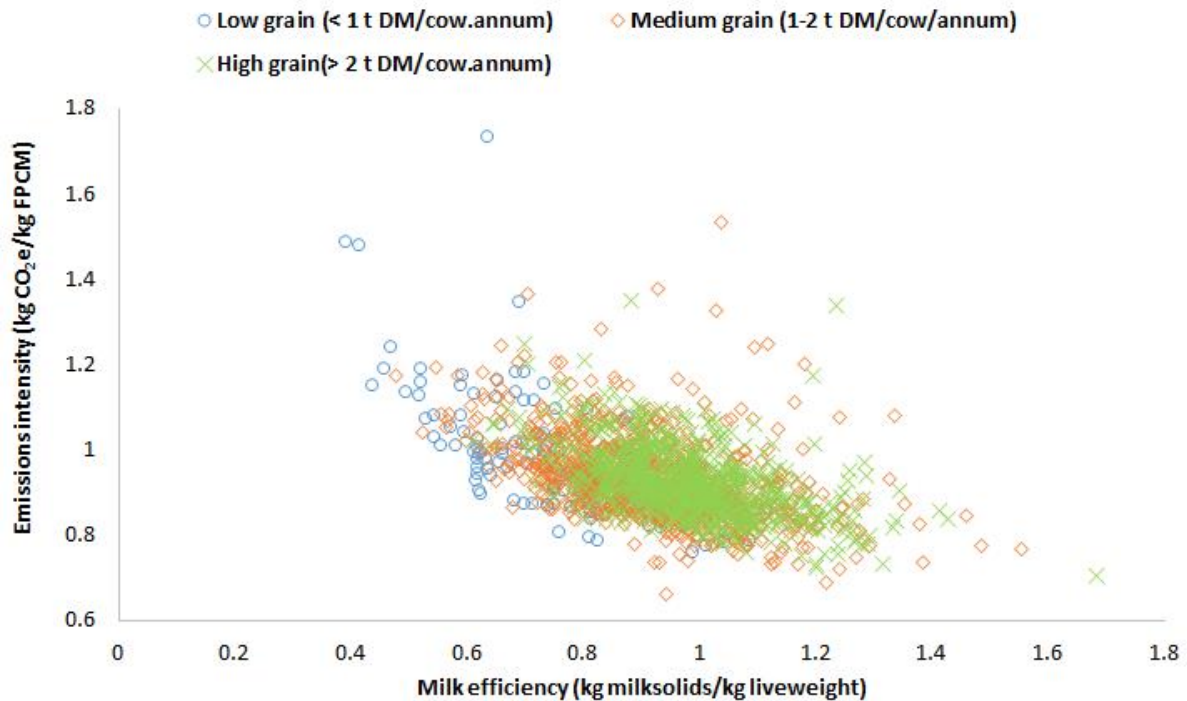


Figure 37. The relationship between milk efficiency (kg milksolids/kg liveweight) and emissions intensity (kg CO₂e/kg FPCM) for low grain feeding (< 1 t DM/cow; blue circles), medium grain feeding (1-2 t DM/cow; orange diamonds), and high grain feeding (> 2 t DM/cow; green crosses).

Another key input to dairy farms that contributes to net GHG emissions is N fertiliser. Figure 38 illustrates the relationship between N fertiliser inputs (kg N/ usable ha) and EI (kg CO₂e/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 lowest N fertiliser group (< 100 kg N/ha) mean EI was 0.92 kg CO₂e/kg FPCM. Mean EI increased to 0.94 kg CO₂e/kg FPCM for the next highest N fertiliser group, while there was no difference in EI with the two groups applying 200+ kg N/ha, at 0.97 kg CO₂e/kg FPCM (Figure 38). However, farms with reasonably high N fertiliser inputs (> 200 kg N/usable ha) can also exhibit a lower-than-average EI. It must be concluded that these farms are excellent at converting N fertiliser into high-quality forage, which is efficiently grazed/conserved, and then converted into milk production, to dilute the GHG emissions associated with N fertiliser inputs. Conversely, low N fertiliser inputs do not necessarily result in a low EI, given approx. one third of the lowest N fertiliser rate group exhibited an EI greater than the long-term average of 0.93 kg CO₂e/kg FPCM (Figure 38).

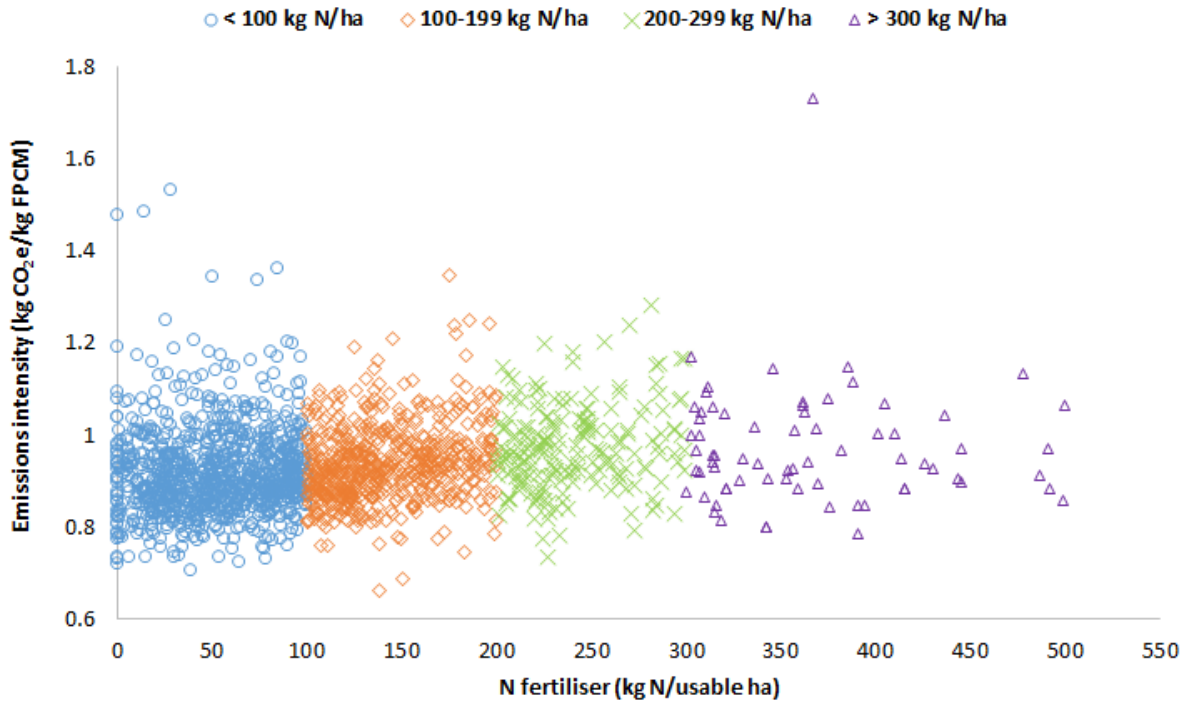


Figure 38. The relationship between N fertiliser inputs (kg N/usable hectare) and emissions intensity (kg CO₂e/kg FPCM) for four N fertiliser ranges. Low (< 100 kg N/ha; blue circles), medium (100-199 kg N/ha; orange diamonds), high (200-299 kg N/ha; green crosses), and very high (> 300 kg N/ha; purple triangles).

One issue with presenting averages is they disguise the variation of results between farms. Figure 39 illustrates the range of EIs for farms in Victoria that have participated for 10+ years over the 15 year period from 2006/07 to 2020/21. The numbers at the top of the chart indicate how many farms are captured in each year of the boxplots. Note 2016/17 had more farms participate in the DFMP. However, only 11 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).

The median (horizontal line in each boxplot) has remained relatively consistent within the 0.90 to 0.95 kg CO₂e/kg FPCM range for all years, except the very first year of 2006/07 (Figure 39). However, there does appear to be a trend in the last 4 years where farms sitting outside of the whiskers (outlier dots beyond the 10th and 90th percentiles) are generally trending down. For example, the maximum EI in FY 2018 was 1.18 kg CO₂e/kg FPCM. In contrast, the maximum EI in FY 2021 was 1.06 kg CO₂e/kg FPCM. Similarly, the lowest EI in FY 2018 was estimated at 0.79 kg CO₂e/kg FPCM and by FY 2021, the lowest EI was 0.66 kg CO₂e/kg FPCM (Figure 39). Several years of additional data would be required to ascertain if the trend over the last 2-3 years continues.

There can be issues with focusing on single dot points within boxplots, in terms of we have no way of gauging the accuracy of data entry. In addition, we cannot determine 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.

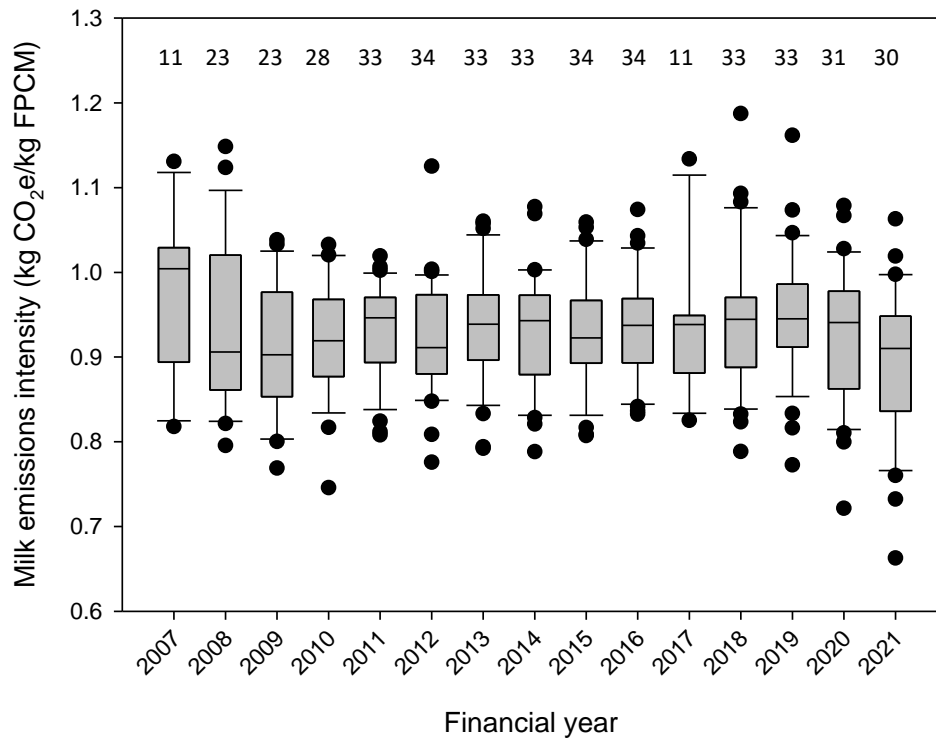


Figure 39. Range of milk emissions intensities, after allocating a proportion of greenhouse gas emissions to meat, across Victorian dairy farms that have participated in 10+ years of the Dairy Farm Monitor Project. The boxplot represents the 25th to 75th percentiles, the whiskers represent the 10th and 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.

7. 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 40) or scroll through all the sheets to locate the sheet you wish to use. These strategies are broadly grouped into four categories:

1. Herd and breeding management options to reduce enteric CH₄ and/or N₂O emissions,
2. Diet manipulation to reduce enteric CH₄ and/or N₂O emissions,
3. Feedbase management to reduce N₂O emissions, and
4. Whole farm abatement to reduce CO₂, CH₄ and/or N₂O 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” sheet. This new sheet contains the baseline farm data, which can now be altered.

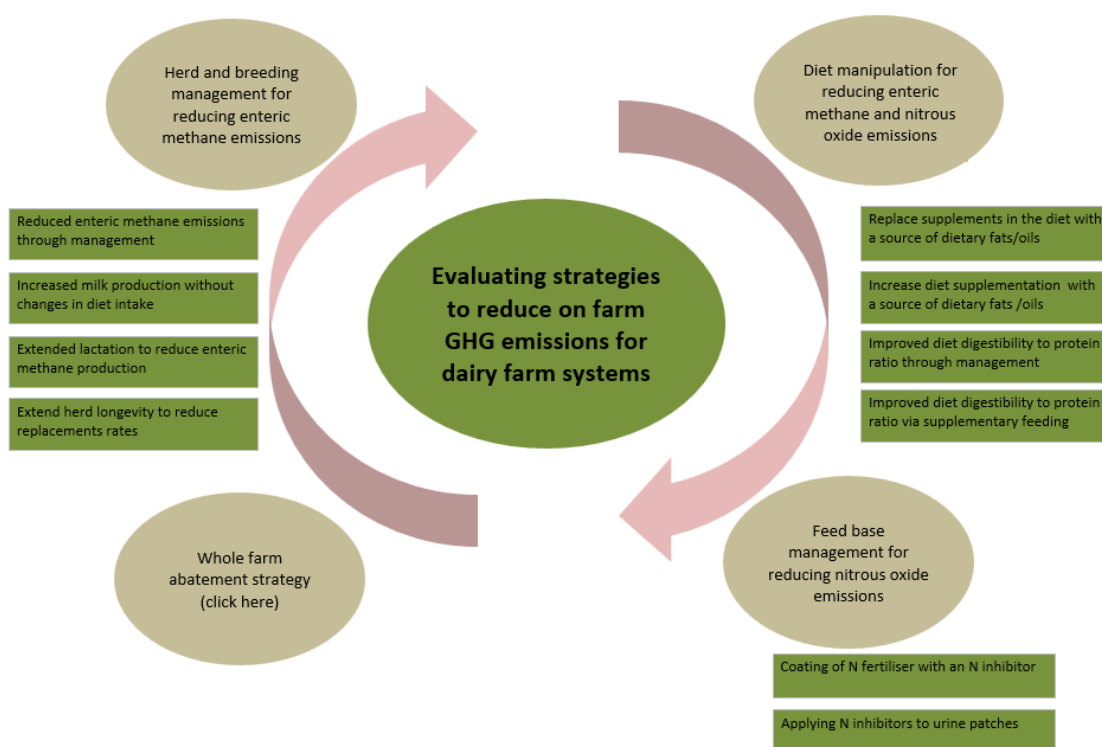


Figure 40. Schematic illustrating the various abatement options that can be explored in the ADCC.

All abatement options have a grey section across the top of their corresponding sheet explaining what the abatement is designed to explore (Figure 41). For example, *Reducing enteric methane emissions through management* explores options that will focus on reducing enteric CH₄ emissions with or without an improvement in milk production. Examples include management options such as a vaccine or feeding a very low dose supplement (e.g. *Asparagopsis* or 3-NOP (Bovaer®)) which will not alter diet DMD% or CP%.

Figure 41 illustrates the explanation of feeding of dietary fats and oils, through increased supplementation.

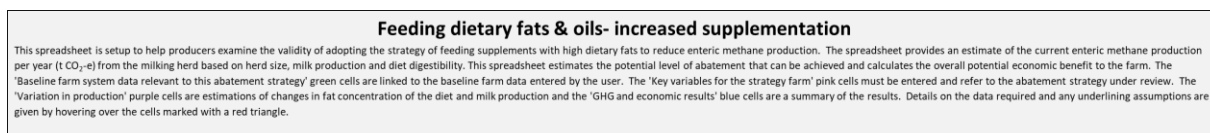


Figure 41. Screenshot of the grey box explaining the “Increase diet supplementation with a source of dietary fats/oils” abatement option.

Following this descriptor section, down the left-hand side of the sheet, is a green box titled **Baseline farm system data relevant to this abatement strategy** (Figure 42). This data is self-populated when entering your baseline farm data, with the one exception. The Extended lactation adaptation option sheet asks for additional information which cannot be gathered when entering the baseline farm data (see section 7.3 for more information specific to Extended lactations).

Baseline farm system data relevant to this abatement strategy	
Baseline number of milkers	450
Average liveweight of milking cow (kg)	500
Current milk production (litres/cow.day)	22.2
Average lactation length (days)	300
Digestibility of the baseline diet (%)	75.7
Crude protein of the baseline diet (%)	18.6

Figure 42. Screenshot of the green box illustrating some key baseline farm data related to the “Increase diet supplementation with a source of dietary fats/oils” abatement option.

Next is a pink box with **Key variables for the strategy farm** (Figure 43). These are a series of questions specific to the abatement strategy being explored. The cells needing data are all coloured white and contain up/down arrows to select the most relevant answer to the question asked. For example, in Figure 43, the first question requires the user to estimate the fat content of the current baseline diet, by using the up/down arrows so that the number in the white cell best matches the required number. The white cells are protected, so the user can only alter the values by using the up/down arrows. 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 your mouse can then correctly click on either the up or down button and values alter accordingly.

In some instances we have separated results into increments of 0.5 (e.g. DMD%), 0.2 (e.g. CP%), or 0.25 (e.g. on-farm price received for a tonne of CO₂e) 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 white cell.

In some instances, you may be clicking on the down arrow of the up/down arrow box. Yet the adjacent value is increasing. If this occurs, increase the display size so to zoom into the sheet more. The easiest way to do this, if you have a mouse attached to the computer, is click on the Ctrl key on your keypad while rolling the scroll wheel. Click in the adjacent white cell where the value is before then moving your mouse to click on the appropriate down or up arrow.

Key variables for the strategy farm		
Enter estimated fat content of the current baseline 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)	300	
Enter estimated substitution rate (range between 0 and 1)	0.80	
Enter average annual milk price (\$/ litre)	\$0.600	
Enter milk price for when supplements fed (\$/litre)	\$0.600	
Enter on farm price received for a t CO ₂ e (\$)	\$30.00	

Figure 43. Screenshot of the pink box 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 white cell.

Next is a purple box with **Variation in production** (Figure 44). This section varies between abatement strategies explored. Where the strategy implemented results in an aspect relevant to milk production, this is reported in this purple section. For example, in Figure 44, the abatement strategy resulted in an estimated extra 88,849 litres of milk produced, relative to the baseline farm system. 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%. In Figure 44, the estimated fat content of the new diet is

5.02%, with milk production estimated to increase by approx. 88,850 litres, based on the changes in the farm system.

Variation in production	
Estimated fat content of the abatement strategy diet (%)	5.02
Estimated additional milk produced (litres/farm)	89,473

Figure 44. Screenshot of the purple box 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 blue box contains **GHG and economic results** (Figure 45). These headings are consistent for all abatement strategies, indicating:

- reduction in emissions,
- 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 baseline milk income.

Each result has a note with information related to the result, as indicated by the red triangle in the top right corner of each result description. A negative reduction in GHG emissions reflects an increase in GHG emissions. For example, in Figure 45 while enteric CH₄ emissions declined by 11.5 t CO₂e/annum, the reduction in animal waste CH₄ was -0.4 t CO₂e, indicating that this source of emissions increased by 0.4 t CO₂e. The carbon credit income was \$427/annum. Given the baseline milk income was estimated as approx. \$1,798,000 (data not shown; based on baseline milk production (litres per annum) x the nominated milk price in the pick section), a carbon credit income of \$427 represents approx. 0.74% of the baseline milk income.

GHG and economic results	
Reduction in enteric CH ₄ emissions (t CO ₂ e/annum)	11.3
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	-0.3
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	3.1
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	0.0
Total reduction in farm GHG emissions (t CO ₂ e/annum)	14.1
Calculated potential carbon credit (\$ per farm)	\$422
Calculated expense to implement the strategy (\$ per farm)	\$40,500
Benefit as stand alone abatement (\$ per farm)	-\$40,078
Estimated additional milk income (\$ per farm)	\$53,684
Estimated total farm benefit from strategy (\$ per farm)	\$13,606
Carbon credit total farm benefit income as % of current milk income	0.76%

Figure 45. Screenshot of the blue box illustrating the change in GHG emissions, costs of implementation, change in income from milk production, and the estimated total farm benefit of implementing the “Increase diet supplementation with a source of dietary fats/oils” abatement option.

Results are also presented graphically (Figure 46), 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 7.8 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.

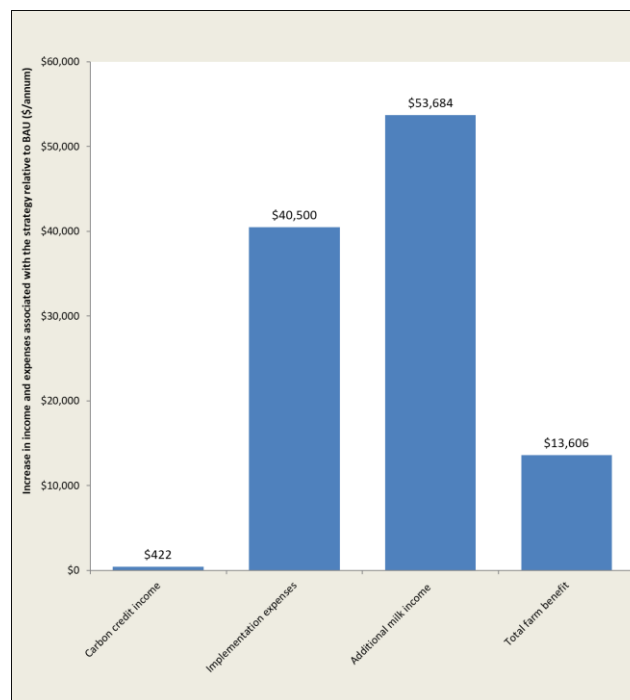


Figure 46. Screenshot of the results of an abatement strategy to reduce enteric methane production through the feeding of dietary fats & oils. The strategy generated \$422 in carbon credits, cost \$40,500/annum to implement, and increased income from milk production by \$53,684/annum, thus total farm benefit was \$13,606/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.

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.

7.1. 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 CH₄ 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 CH₄ 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 CH₄ through breeding or management* to now allow a combination of options to be explored.

- a) Management option where animal produce lower CH₄ emissions per unit of feed intake, through a vaccine or feeding small amounts of additives which reduces enteric CH₄ emissions (e.g. *Asparagopsis* or 3-NOP trading as *Bovaer*[®]). This option may or may not result in any improvement in milk production, relative to the baseline farm system,
- b) Breeding option where animals are genetically superior, thus either producing less CH₄ 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 CH₄ 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 CH₄ emissions, it will affect waste CH₄ 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 CH₄ emissions. Another example is that if the diet's CP% increases, relative to the baseline, the amount of N excreted in urine will also increase, resulting in an increase in waste N₂O 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 CH₄ emissions, you need to progress to either section 7.4 or 7.5 where overall diet quality may alter.

We have not incorporated a reduction in enteric CH₄ 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 pink key variables section to determine the percentage reduction in enteric CH₄ 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 CO₂e (Figure 47).

How are the results of the strategy calculated?

Within the spreadsheet, the enteric CH₄ 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 CH₄ emissions from 20.7 g CH₄/kg DMI to 14.5 g CH₄/kg DMI (i.e. $20.7 \times (1 - 30\% \text{ reduction potential}) \times (365 \text{ days effective} / 365 \text{ days of the year})$). If diet DMD% changes, this will not alter diet intakes and subsequently enteric CH₄ emissions. However, it will alter waste CH₄ emissions as per the inventory, as will any changes in diet CP%. Increases in milk production will alter waste N₂O 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 CH₄ and improve milk production without a change in diet quality

In the example below (Figure 47), a vaccine reduced CH₄ 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 \$0.60/litre, while the on-farm price for a reduction in CO₂e emission (after additional administrative costs) was \$30/t CO₂e. 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 CO₂e/annum, mainly enteric CH₄ emissions. The annum total farm benefit was \$70,308, based on a carbon credit of \$12,258, an additional milk income of \$64,800 and an implementation cost of \$6,750 (Figure 47). The net change in farm income, relative to the baseline milk income, was estimated at 3.91% (Figure 47). In addition, in reality, 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 %	<input checked="" type="radio"/> No <input type="radio"/> Yes	
Enter new annual diet dry matter digestibility (%)	75.7	
Enter new annual diet crude protein (%)	18.7	
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)	\$0.60	
Enter on farm price received for a t CO ₂ e (\$)	\$30.00	
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 ₂ e/annum)	406.7	
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	0.0	
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	1.9	
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	0.0	
Total reduction in farm GHG emissions (t CO ₂ e/annum)	408.6	
Calculated potential carbon credit (\$ per farm)	\$12,258	
Calculated expense to implement the strategy (\$ per farm)	\$6,750	
Benefit as stand alone abatement (\$ per farm)	\$5,508	
Estimated additional milk income (\$ per farm)	\$64,800	
Estimated total farm benefit from strategy (\$ per farm)	\$70,308	
Carbon credit total farm benefit income as % of baseline milk income	3.91%	

Figure 47. Screenshot of the key variables (pink section), variation in production (purple section; milk production in this instance), and GHG and economic results of implementing a strategy to reduce enteric CH₄ emissions through management, a vaccine in this instance but could be any intervention that reduced enteric CH₄ (blue section).

b) *Breeding option to increase milk production with no change in enteric CH₄ or diet quality*

In Figure 48, 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 CH₄ emissions or diet quality. Therefore, unlike most other interventions, this example does not really result in a noticeable reduction in GHG emissions. Similar to 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 baseline farm system). This allows a direct comparison to Figure 47 above where enteric CH₄ emissions were reduced. The milk price was set at \$0.60/litre, while the on-farm price for a reduction in CO₂e emission (after additional administrative costs) was \$30/t CO₂e. Similar to that explored in Figure 47, the strategy resulted in an additional 108,000 litres of milk per annum. However, there was now only the small reduction in waste N₂O emissions, due to more nitrogen being exported off farm in milk. The annum

total farm benefit was \$58,106 based on a carbon credit of \$56, an additional milk income of \$64,800 and an implementation cost of \$6,750 (Figure 48). 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 baseline milk income, was estimated at 3.23% (Figure 48), as there was little change in GHG emissions, relative to the baseline, so a lower net profit. In addition, in reality, 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	<input type="text"/>
Enter improvement in milk production (litres per cow per day)	0.80	<input type="text"/>
Is there any change in diet dry matter digestibility and/ or crude protein %	<input checked="" type="radio"/> No <input type="radio"/> Yes	
Enter new annual diet dry matter digestibility (%)	75.7	<input type="text"/>
Enter new annual diet crude protein (%)	18.6	<input type="text"/>
Enter cost of implementing the abatement strategy (\$ per cow per annum)	\$15.00	<input type="text"/>
Enter number of days per year that the abatement strategy is effective for	300	<input type="text"/>
Enter average annual milk price (\$/ litre)	\$0.60	<input type="text"/>
Enter on farm price received for a t CO ₂ e (\$)	\$30.00	<input type="text"/>
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 ₂ e/annum)	0.0	
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	0.0	
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	1.9	
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	0.0	
Total reduction in farm GHG emissions (t CO ₂ e/annum)	1.9	
Calculated potential carbon credit (\$ per farm)	\$56	
Calculated expense to implement the strategy (\$ per farm)	\$6,750	
Benefit as stand alone abatement (\$ per farm)	-\$6,694	
Estimated additional milk income (\$ per farm)	\$64,800	
Estimated total farm benefit from strategy (\$ per farm)	\$58,106	
Carbon credit total farm benefit income as % of baseline milk income	3.23%	

Figure 48. Screenshot of the key variables (pink section), variation in production (purple section; milk production in this instance), and GHG and economic results of implementing a strategy to improve milk production through a breeding option (blue section).

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 49, 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 baseline 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 baseline 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 a baseline of 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 taken into account 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 \$0.60/litre, while the on-farm price for a reduction in CO₂e emission (after additional administrative costs) was \$30/t CO₂e. Unlike in Figures 47 and 48, 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 CH₄ of 13.1 t CO₂e. The decline in overall diet CP along with more nitrogen being exported off farm with the increase in milk production resulted in a 19.3 t CO₂e decline in waste N₂O emissions, thus net farm emissions declined by 32.3 t CO₂e/annum. The annum total farm benefit was \$45,520, based on a carbon credit of \$970, an additional milk income of \$44,550 with no cost of implementation (Figure 49). The net change in farm income, relative to the baseline milk income, was estimated at 2.53% (Figure 49). In addition, in reality, 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	<input type="text"/>
Enter improvement in milk production (litres per cow per day)	0.55	<input type="text"/>
Is there any change in diet dry matter digestibility and/ or crude protein %	<input type="radio"/> No <input checked="" type="radio"/> Yes	
Enter new annual diet dry matter digestibility (%)	76.8	<input type="text"/>
Enter new annual diet crude protein (%)	17.6	<input type="text"/>
Enter cost of implementing the abatement strategy (\$ per cow per annum)	\$0.00	<input type="text"/>
Enter number of days per year that the abatement strategy is effective for	300	<input type="text"/>
Enter average annual milk price (\$/ litre)	\$0.60	<input type="text"/>
Enter on farm price received for a t CO ₂ e (\$)	\$30.00	<input type="text"/>
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 ₂ e/annum)	0.0	
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	13.1	
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	19.3	
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	0.0	
Total reduction in farm GHG emissions (t CO ₂ e/annum)	32.3	
Calculated potential carbon credit (\$ per farm)	\$970	
Calculated expense to implement the strategy (\$ per farm)	\$0	
Benefit as stand alone abatement (\$ per farm)	\$970	
Estimated additional milk income (\$ per farm)	\$44,550	
Estimated total farm benefit from strategy (\$ per farm)	\$45,520	
Carbon credit total farm benefit income as % of baseline milk income	2.53%	

Figure 49. Screenshot of the key variables (pink section), variation in production (purple section; 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 CH₄ and N₂O emissions (blue section).

7.2. 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 CH₄ 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 N₂O 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 baseline 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 50). 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.

Baseline farm system data relevant to this abatement strategy	
Baseline number of milkers	450
Average liveweight of mature milking cow (kg)	500
Average daily milk production during the 1 st 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 50. Screenshot of the additional baseline farm system data required for the Extended lactation abatement strategy.

Users must enter the calving date in the pink 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 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 CO₂e (Figure 51).

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. Users may view the estimations by accessing the spreadsheet, at their own risk, by unprotecting the sheet (password is Dairy_ADCC), then unhiding the rows from 63 onwards. 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 51), the comparison commenced 1/7/2021 for the baseline 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 baseline 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 baseline 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 \$50/lactation compared to their baseline counterparts. The milk price was set at \$0.60/litre, while the on-farm price for a reduction in CO₂e emission (after additional administrative costs) was \$30/t CO₂e.

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 CH₄ 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 \$14,190, based on a carbon credit of \$34, an additional milk income of \$29,170, and an implementation cost of \$15,014 (Figure 51). The net change in farm income, relative to the baseline milk income, was estimated at 0.77% (Figure 51). In addition, in reality, the extra milk might require more electricity for milking and cooling, further reducing net profits as well as GHG emissions from electricity usage.

In this example, a quick use of the up/down arrows in the pink section illustrated that if the additional cost to implement was greater than ~ \$100/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 as opposed to 22 months explored there could result in a different outcome to that presented here.

Key variables for the strategy farm	
Enter calving date for start of lactation comparison (format dd/mm/yyyy)	1/07/2021
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	4
Enter the cost to implement (\$ per cow per lactation)	50
Enter average annual milk price (\$/ litre)	\$0.60
Enter on farm price received for a t CO ₂ e (\$)	\$30.00
Variation in production	
Estimated additional milk produced (litres/cow.lifetime)	588
Estimated additional milk produced (litres/herd.annum)	48,616
GHG and economic results	
Reduction in enteric CH ₄ emissions (t CO ₂ e/annum)	1.1
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	0.0
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	0.0
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	0.0
Total reduction in farm GHG emissions (t CO ₂ e/annum)	1.1
Calculated potential carbon credit (\$ per farm)	\$34
Calculated expense to implement the strategy (\$ per farm)	\$15,014
Benefit as stand alone abatement (\$ per farm)	-\$14,980
Estimated additional milk income (\$ per farm)	\$29,170
Estimated total farm benefit from strategy (\$ per farm)	\$14,190
Carbon credit total farm benefit income as % of current milk income	0.77%

Figure 51. Screenshot of the key variables (pink section), variation in production (purple section; milk production in this instance), and GHG and economic results of implementing a strategy of extended lactations to reduce enteric CH₄ emissions (blue section).

7.3. 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 CH₄, waste CH₄, and N₂O emissions.

Key variables for the strategy farm

There are several questions in the pink 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 CO₂e (Figure 52).

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 baseline farm system.

Example of results

In the example below (Figure 52), we have reduced the number of Rising 2 yr old heifers from ~ 120 down to ~ 100 and Rising 1 yr old heifers from 125 to 105. This resulted in the herd replacement rate declining from 27 to 22% (shown in the purple section of Figure 52). The cost to raise a heifer to the point of calving was estimated at \$1,800/head. The milk price was set \$0.60/litre, while the on-farm price for a reduction in CO₂e emission (after additional administrative costs) was \$30/t CO₂e.

Total GHG emissions were reduced by 35.4 t CO₂e/annum. Total farm benefit was \$37,063, based on a carbon credit of \$1,063, and a savings of \$36,000 per annum because we were no longer raising an additional 20 heifers per age group each year, coupled with no change in herd milk production (Figure 52). The net change in farm income, relative to the baseline milk income, was estimated at 2.06% (Figure 52).

Key variables for the strategy farm		
Enter number of heifers > 1 yr age	▼	100
Enter number of heifers < 1 yr age	▼	105
Enter the price to raise a heifer calf to the point of joining the milking herd (\$/head)	▼	1800
Enter average annual milk price (\$/ litre)	▼	\$0.60
Enter on farm price received for a t CO2e (\$)	▼	\$30.00
Variation in production		
Estimated baseline replacement rate		27%
Estimated strategy replacement rate		22%
GHG and economic results		
Reduction in enteric CH4 emissions (t CO2e/annum)	▼	27.8
Reduction in animal waste CH4 emissions (t CO2e/annum)	▼	0.6
Reduction in animal waste N2O emissions (t CO2e/annum)	▼	7.0
Reduction in N fertiliser N2O emissions (t CO2e/annum)	▼	0.0
Total reduction in farm GHG emissions (t CO2e/annum)	▼	35.4
Calculated potential carbon credit (\$ per farm)	▼	\$1,063
Calculated expense to implement the strategy (\$ per farm)	▼	-\$36,000
Benefit as stand alone abatement (\$ per farm)	▼	\$37,063
Estimated additional milk income (\$ per farm)	▼	\$0
Estimated total farm benefit from strategy (\$ per farm)	▼	\$37,063
Carbon credit total farm benefit income as % of current milk income	▼	2.06%

Figure 52. Screenshot of the key variables (pink section), variation in production (purple section; 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.

7.4. 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 CH₄ emissions. It has been shown that enteric CH₄ 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 CH₄ emissions. This strategy assumes that an amount of baseline 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 7.5).

Key variables for the strategy farm

There are many questions in the pink key variables section to ascertain (Figure 53). Firstly, the fat content of the baseline diet is not captured during the data entry period for the baseline 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) in the Resources section for common grain and by-products or accessing <https://www.feedipedia.org/node/742> 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 baseline supplement replaced with a high dietary fat supplement, the costs of the baseline 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 CO₂e (Figure 53).

How are the results of the strategy calculated?

The feeding of dietary fats is used to be an ERF method project (<https://www.cleanenergyregulator.gov.au/ERF/Choosing-a-project-type/Opportunities-for-the-land-sector/Agricultural-methods/Reducing-Greenhouse-Gas-Emissions-by-Feeding-Dietary-Additives-to-Milking-Cows>). 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 baseline farm enteric CH₄. Thus, for this strategy, COST re-estimates the baseline farm enteric CH₄ emissions, and compares this to the strategy farm enteric CH₄ emissions, both following the ERF project methodology. Enteric CH₄ (g CH₄/kg DMI) is calculated as $24.51 - 0.0788 \times \text{dietary fat \%}$ 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 CH₄ 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 CH₄ emissions. Likewise, if the CP of the new overall diet increases, waste N₂O emissions will also increase. However, the methodology does not recognise a decrease in overall diet CP which should allow for a reduction in waste N₂O emissions.

Example of results

In the example below (Figure 53), 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 baseline 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 purple section of Figure 50). The high-fat supplement was higher in DMD (80% vs 72% for the silage), thus milk production increased by 60,200 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 silage. The milk price was set at \$0.60/litre, while the on-farm price for a reduction in CO₂e emission (after additional administrative costs) was \$30/t CO₂e. 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 CH₄ emissions declined by 32.3 t CO₂e/annum. Total farm benefit was \$23,588, based on a carbon credit of \$968, an additional milk income of \$36,120, and an implementation cost of \$13,500 (Figure 53). The net change in farm income, relative to the baseline milk income, was estimated at 1.31% (Figure 51). In addition, in reality, 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 estimated fat content of the baseline diet (%)	4.0	
Enter amount of baseline supplement to be replaced (kg DM/cow.day)	4.0	
Enter digestibility of baseline supplement to be replaced (%)	72.0	
Enter crude protein of the baseline supplement to be replaced (%)	17.0	
Enter fat content of baseline supplement to be replaced (%)	3.0	
Enter cost of baseline supplement to be replaced (\$/t DM)	250	
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)	300	
Enter number of days per year the new abatement supplement is fed	150	
Enter average annual milk price (\$/ litre)	\$0.600	
Enter milk price for when supplements fed (\$/litre)	\$0.600	
Enter on farm price received for a t CO ₂ e (\$)	\$30.00	
Variation in production		
Estimated fat content in the abatement strategy diet during the activation period (%)	5.62	
Estimated additional milk produced (litres/farm)	60,200	
GHG and economic results		
Reduction in enteric CH ₄ emissions (t CO ₂ e/annum)	32.3	
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	0.0	
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	0.0	
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	0.0	
Total reduction in farm GHG emissions (t CO ₂ e/annum)	32.3	
Calculated potential carbon credit (\$ per farm)	\$968	
Calculated expense to implement the strategy (\$ per farm)	\$13,500	
Benefit as stand alone abatement (\$ per farm)	-\$12,532	
Estimated additional milk income (\$ per farm)	\$36,120	
Estimated total farm benefit from strategy (\$ per farm)	\$23,588	
Carbon credit total farm benefit income as % of current milk income	1.31%	

Figure 53. Screenshot of the key variables (pink section), variation in production (purple section; 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.

7.5. 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 CH₄ emissions. This strategy differs to the previous one (section 7.4) in that here, we assume an increase in supplementary feeding to increase overall dietary intake.

It has been shown enteric CH₄ 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 CH₄ emissions, and potentially alter waste CH₄ and N₂O emissions, depending on overall diet quality changes.

Key variables for the strategy farm

There are many questions in the pink key variables section to ascertain (Figure 54). Firstly, the fat content of the baseline diet is not captured during the data entry period for the baseline 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) in the Resources section for common grain and by-products or accessing <https://www.feedipedia.org/node/742> 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 CO₂e (Figure 54).

How are the results of the strategy calculated?

Unlike the previous section 7.4, this strategy retains the same methodology for estimating GHG emissions as per the baseline farm system. The calculator determines the new diet quality parameters to estimate CH₄ and N₂O 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, 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 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 baseline 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 7.4. Therefore, if the overall diet DMD% improves with the new high-fat supplement, this can reduce waste CH₄ emissions and is included in the net change in GHG emissions. If the CP% of the new higher fat diet decreases, so too will N₂O emissions. Conversely, if the new higher fat diet is higher in CP% than the baseline diet, N₂O emissions will increase accordingly.

Example of results

In the example below (Figure 54), 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 baseline diet (i.e. 2 kg DM x 0.8 = 1.6 kg DM) with the high-fat supplement. For example, if the baseline farm system cows were consuming 15 kg DM/day, they now consume 13.4 kg DM/day of the baseline 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 baseline 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 baseline 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 baseline 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 baseline 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 baseline diet) and cost \$300/t DM. The milk price was set at \$0.60/litre, and the on-farm price for a reduction in CO₂e emission (after additional administrative costs) was \$30/t CO₂e. 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 14.1 t CO₂e/annum, due to a reduction in enteric CH₄ emissions, and N₂O emissions to a lesser extent. While the diet DMD% increased, so too did intakes and milk production, thus increasing waste CH₄ production. Total farm benefit was \$13,733, based on a carbon credit of \$427, an additional milk income of \$53,806, and an implementation cost of \$40,500 (Figure 54). The net change in farm income, relative to the baseline milk income, was estimated at 0.76% (Figure 54). In addition, in reality, 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 estimated fat content of the current baseline diet (%)	4.0	<input type="text"/>
Enter amount of additional supplement to be fed (kg DM/cow.day)	2.0	<input type="text"/>
Enter digestibility of the additional supplement fed (%)	80.0	<input type="text"/>
Enter crude protein of the additional supplement fed (%)	12.0	<input type="text"/>
Enter estimated fat content of the supplement fed (%)	13.0	<input type="text"/>
Enter number of days the fat source is fed (days/year)	150	<input type="text"/>
Enter cost of additional supplementary feed (\$/t DM)	300	<input type="text"/>
Enter estimated substitution rate (range between 0 and 1)	0.80	<input type="text"/>
Enter average annual milk price (\$/ litre)	\$0.600	<input type="text"/>
Enter milk price for when supplements fed (\$/litre)	\$0.600	<input type="text"/>
Enter on farm price received for a t CO ₂ e (\$)	\$30.00	<input type="text"/>
Variation in production		
Estimated fat content of the abatement strategy diet (%)	5.02	
Estimated additional milk produced (litres/farm)	89,676	
GHG and economic results		
Reduction in enteric CH ₄ emissions (t CO ₂ e/annum)	11.3	
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	-0.3	
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	3.2	
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	0.0	
Total reduction in farm GHG emissions (t CO ₂ e/annum)	14.2	
Calculated potential carbon credit (\$ per farm)	\$427	
Calculated expense to implement the strategy (\$ per farm)	\$40,500	
Benefit as stand alone abatement (\$ per farm)	-\$40,073	
Estimated additional milk income (\$ per farm)	\$53,806	
Estimated total farm benefit from strategy (\$ per farm)	\$13,733	
Carbon credit total farm benefit income as % of current milk income	0.76%	

Figure 54. Screenshot of the key variables (pink section), variation in production (purple section; 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 CH₄ and N₂O emissions.

7.6. 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 CH₄, along with waste CH₄ and N₂O 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 N₂O 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), and irrigation infrastructure. We do not stipulate how the overall diet energy to protein ratio is achieved here. Section 7.7 explores DMD to CP ratio changes through supplementary feeding options.

Key variables for the strategy farm

The pink 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 CO₂e (Figure 55). 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 real 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 55), we assumed the intervention was a combination of better grazing management but also included reseeding several paddocks with a high sugar ryegrass with 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 baseline DMD to CP ratio was 4.1 while the strategy ratio increased to 4.6. The better grazing management did not incur any additional costs, but the reseeding on paddocks incurred an additional \$5,000/annum above baseline annual reseeding costs. The milk price was set at \$0.60/litre, and the on-farm price for a reduction in CO₂e emission (after additional administrative costs) was \$30/t CO₂e. In this example, enteric CH₄ emissions increased (i.e. a negative reduction in enteric CH₄ values) due to increased milk production. However, waste CH₄ emissions declined due to improved diet digestibility. Waste N₂O emissions also declined as

there was less N excreted in urine, resulting in a net reduction in total GHG emissions of 31.6 t CO₂e/annum. Total farm benefit was \$156,199, based on a carbon credit of \$947, an additional milk income of \$160,253, and an implementation cost of \$5,000 (Figure 55). The net change in farm income, relative to the baseline milk income, was at 8.68% (Figure 55). In addition, in reality, 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 digestibility of the abatement strategy diet (%)	78.0	<input type="text"/>
Enter crude protein of the abatement strategy diet (%)	17.0	<input type="text"/>
Enter time period of improved diet digestibility (number of days per year)	365	<input type="text"/>
Enter cost of achieving improved diet digestibility to protein ratio (\$/ annum)	\$5,000	<input type="text"/>
Enter average annual milk price (\$/ litre)	\$0.600	<input type="text"/>
Enter milk price for when increased diet DMD is available (\$/ litre)	\$0.600	<input type="text"/>
Enter on farm price received for a t CO ₂ e (\$)	\$30.00	<input type="text"/>
Variation in production		
Estimated change in daily diet energy (MJ/cow.day)	8.94	
Estimated additional milk produced (litres/farm per annum)	267,088	
GHG and economic results		
Reduction in enteric CH ₄ emissions (t CO ₂ e/annum)	-20.2	▼
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	23.1	▼
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	28.6	▼
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	0.0	▼
Total reduction in farm GHG emissions (t CO ₂ e/annum)	31.6	▼
Calculated potential carbon credit (\$ per farm)	\$947	▼
Calculated expense to implement the strategy (\$ per farm)	\$5,000	▼
Benefit as stand alone abatement (\$ per farm)	-\$4,053	▼
Estimated additional milk income (\$ per farm)	\$160,253	▼
Estimated total farm benefit from strategy (\$ per farm)	\$156,199	▼
Carbon credit total farm benefit income as % of current milk income	8.68%	▼

Figure 55. Screenshot of the key variables (pink section), variation in production (purple section; 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 CH₄ and N₂O emissions.

7.7. 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 CH₄, along with waste CH₄ and N₂O emissions. Other strategies, such as section 7.6 explored other management options to improve the DMD to CP ratio of the diet, whereas sections 7.4 and 7.5 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 N₂O 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 pink 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 CO₂e (Figure 56).

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 baseline 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 baseline 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 56), we increased grain feeding with a DMD of 82% and CP of 12% and this was fed over 150 days per annum with a 1.0 substitution rate (i.e. we replaced 2 kg DM of silage with 2 kg DM of grain). The baseline 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 \$150/t DM (i.e. silage cost \$150/t DM vs grain was \$300/t DM, considering wastage of silage fed in the paddock vs grain in the dairy shed). The milk price was set at \$0.60/litre, and the on-farm price for a

reduction in CO₂e emission (after additional administrative costs) was \$30/t CO₂e. In this example, enteric CH₄ emissions increased by 3.5 t CO₂e (shown as a negative value in Figure 56) due to increased intakes associated with additional milk production. However, waste CH₄ declined due to the increased DMD% of the diet offsetting the additional intake due to increased milk production. Waste N₂O emissions declined, as there was less N in the diet, and thus excreted in urine. Net total GHG emissions decreased by 4.0 t CO₂e/annum. Total farm benefit was -\$5,149 based on a carbon credit of \$119, an additional milk income of \$14,982, and an implementation cost of \$20,250 (Figure 56). The net change in farm income, relative to the baseline milk income, was estimated at -0.29%, further illustrating the decline in income with this intervention due to the high implementation cost (Figure 56). In addition, in reality, the extra milk might require more electricity for milking and cooling, further reducing net profits as well as GHG emissions from electricity usage.

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, thus increasing enteric CH₄ 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 CH₄ has not altered, you could model this scenario as per section 7.1, 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)	▼	150
Enter average annual milk price (\$/ litre)	▼	\$0.600
Enter milk price for when supplements fed (\$/litre)	▼	\$0.600
Enter on farm price received for a t CO ₂ e (\$)	▼	\$30.00
Variation in production		
Estimated change in ME intake (MJ/cow.day)		2.0
Estimated additional milk produced (litres/farm)		24,969
GHG and economic results		
Reduction in enteric CH ₄ emissions (t CO ₂ e/annum)	▼	-3.5
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	▼	2.8
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	▼	4.8
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	▼	0.0
Total reduction in farm GHG emissions (t CO ₂ e/annum)	▼	4.0
Calculated potential carbon credit (\$ per farm)	▼	\$119
Calculated expense to implement the strategy (\$ per farm)	▼	\$20,250
Benefit as stand alone abatement (\$ per farm)	▼	-\$20,131
Estimated additional milk income (\$ per farm)	▼	\$14,982
Estimated total farm benefit from strategy (\$ per farm)	▼	-\$5,149
Carbon credit total farm benefit income as % of current milk income	▼	-0.29%

Figure 56. Screenshot of the key variables (pink section), variation in production (purple section; 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 CH₄ and N₂O emissions.

7.8. 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 pink 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 57). 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 pink section, and the baseline 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 baseline 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 57), we assumed 30% of the total N fertiliser applied to pastures was coated with the inhibitor, while the inhibitor fertiliser reduced N₂O 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 ~ 32,000 litres of milk). The milk price was set at \$0.60/litre, and the on-farm price for a reduction in CO₂e emission (after additional administrative costs) was \$30/t CO₂e.

In this example, enteric CH₄ emissions increased due to the inhibitor resulting in more pasture being grown and consumed. Nitrogen fertiliser N₂O emissions declined because of the inhibitor, and by an amount greater than the increase in enteric CH₄ emissions. Thus, total emissions declined by 9.5 t CO₂e/annum. Total farm benefit was \$16,062, based on a carbon credit of \$286, an additional milk income of \$19,076, and an implementation cost of \$3,300 (Figure 57). The net change in farm income, relative to the baseline milk income, was estimated at 0.89% (Figure 57). In addition, in reality, the extra milk might require more electricity for milking and cooling, further reducing net profits as well as GHG emissions from electricity usage.

If there was no additional pasture produced because of the inhibitor, enteric CH₄ emissions would not alter compared to the baseline farm, thus the reduction in N₂O losses would generate a 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 N₂O 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 (not assessed in COST).

Key variables for the strategy farm		
Enter % annual N fertiliser purchased that is coated with an inhibitor	30%	<input type="text"/>
Enter % of the coated fertiliser applied when inhibitor is reducing N ₂ O emissions	100%	<input type="text"/>
Enter % reduction of N ₂ O emissions with inhibitor applied to fertiliser	40%	<input type="text"/>
Enter cost of uncoated fertiliser (\$ / t N)	\$1,300	<input type="text"/>
Enter cost of coated fertiliser (\$ / t N)	\$1,500	<input type="text"/>
Enter additional pasture growth achieved with the inhibitor (kg DM/ha per annum)	200	<input type="text"/>
Enter area of farm that the coated fertiliser is applied to (ha)	100	<input type="text"/>
Enter feed quality of the additional pasture (MJ ME/kg DM)	11	<input type="text"/>
Enter utilisation efficiency of additional pasture (%)	75	<input type="text"/>
Enter average annual milk price (\$/ litre)	\$0.600	<input type="text"/>
Enter milk price for when increased pasutre ME/ diet DMD is available (\$/ litre)	\$0.600	<input type="text"/>
Enter on farm price received for a t CO ₂ e (\$)	\$30.00	<input type="text"/>
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 ₂ e/annum)	-8.7	
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	0.0	
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	0.0	
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	18.2	
Total reduction in farm GHG emissions (t CO ₂ e/annum)	9.5	
Calculated potential carbon credit (\$ per farm)	\$286	
Calculated expense to implement the strategy (\$ per farm)	\$3,300	
Benefit as stand alone abatement (\$ per farm)	-\$3,014	
Estimated additional milk income (\$ per farm)	\$19,076	
Estimated total farm benefit from strategy (\$ per farm)	\$16,062	
Carbon credit total farm benefit income as % of current milk income	0.89%	

Figure 57. Screenshot of the key variables (pink section), variation in production (purple section; 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 N₂O losses, alter milk production, and enteric CH₄ emissions.

7.9. 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 N₂O loss if we could dose the animal with the NI, thus retaining urinary N in the ammonium (NH₄) form for longer, slowing down the denitrification process where NH₄ converts into nitrate (NO₃), and subsequently into N₂O. This contrasts with applying an inhibitor to N-based fertilisers (see section 7.8), along the desired outcome is the same; reducing the rapidity of NH₄ converting to N₂O.

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 N₂O (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 N₂O (indirect). This means any form of retaining N fertiliser in the NH₄ 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 N₂O 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 pink 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 CO₂e (Figure 58). 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 N₂O 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 58), we assumed the cows spent 85% of their time grazing pasture (balance at the dairy, on a feedpad etc). The nitrification inhibitor effectively reduced N₂O losses for 180 days per annum, reducing N₂O losses by 30%. The cost of implementation was \$5/cow per annum, and any reduction in net GHG emissions was valued at \$30/t CO₂e (Figure 58). Total farm benefit was -\$1,517, based on a carbon credit of \$733, and an implementation cost of \$2,250. The net change in farm income, relative to the baseline milk income, was estimated at -0.08% due to the

higher cost to implement relative to any income derived from reducing GHG emissions (Figure 58). By using the scroll up/down arrows, we could quickly determine that a

carbon price of ~ \$93/t CO₂e would be needed for this strategy to become cost neutral, if the cost to implement was \$5/cow per annum. Conversely, an implementation cost of ~ \$1.60/cow per annum would be required to make this abatement option financially viable, based on a carbon price of \$30/t CO₂e.

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)	180	
Enter efficacy of nitrification inhibitor (%)	30	
Enter cost to implement strategy (\$ per cow per annum)	\$5.00	
Enter average annual milk price (\$/ litre)	\$0.600	
Enter on farm price received for a t CO ₂ e (\$)	\$30.00	
Variation in production		
Estimated additional milk produced (litres/farm)	0	
GHG and economic results		
Reduction in enteric CH ₄ emissions (t CO ₂ e/annum)	0.0	
Reduction in animal waste CH ₄ emissions (t CO ₂ e/annum)	0.0	
Reduction in animal waste N ₂ O emissions (t CO ₂ e/annum)	24.4	
Reduction in N fertiliser N ₂ O emissions (t CO ₂ e/annum)	0.0	
Total reduction in farm GHG emissions (t CO ₂ e/annum)	24.4	
Calculated potential carbon credit (\$ per farm)	\$733	
Calculated expense to implement the strategy (\$ per farm)	\$2,250	
Benefit as stand alone abatement (\$ per farm)	-\$1,517	
Estimated additional milk income (\$ per farm)	\$0	
Estimated total farm benefit from strategy (\$ per farm)	-\$1,517	
Carbon credit total farm benefit income as % of current milk income	-0.08%	

Figure 58. Screenshot of the key variables (pink section), variation in production (purple section; 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 N₂O losses.

7.10. Whole-farm abatement strategy

The above-mentioned abatement strategies targeted a specific part of the farm system to alter CH₄ and/or N₂O emissions. The whole-farm abatement strategy differs from all others, in that users can alter one or more aspects of the baseline 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” sheet is automatically populated with the data you enter on the baseline farm data sheet. All entry cells will be white and unprotected. Each white cell has an equation linking back to the “baseline farm” sheet. For example, the milking herd size cell has =‘Baseline farm’!D18 indicating the number here is the same as that found in cell D18 of the baseline farm sheet. This equation will be lost if users enter new data over any of the white 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 baseline farm system sheet, the four questions on the left-hand side of this section **ARE NOT** linked back to the baseline farm system, due to the need for complex equations to be able to select another region, tree species and/or soil type compared to the baseline farm system. The most common example would be that the baseline farm system had Tasmanian Blue Gums and the user wants to explore the option of replacing these with Environmental plantings. Users are less likely to alter soil type or region, however, they may wish to explore the implications of having the exact same farm and trees but in another region of their state. Therefore, if you do have trees present in our baseline farm, you will need to select these again for the strategy farm. The colouring of the cells will alter to indicate when the baseline and strategy farm data entry matches (white cell/ black text) or alters (red cell/white text).

We suggest the best way to manage this sheet is to alter the equation so you can revert to the original baseline numbers as required. For example, if we wanted to milk 50 more cows than the baseline farm, change the Strategy farm equation in D19 to =‘Baseline farm’!D18+50. Conversely, if you wanted to milk 50 less cows than the baseline farm, change the Strategy farm equation in D18 to =‘Baseline farm’!D18-50. When the cell answer is altered, relative to the baseline farm system, the cell changes colour from white to red, while the text alters from black to white. This allows users to quickly identify which aspects of the sheet have been altered (Figure 59). 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 baseline value, and the format will revert back to a white cell with black text.

If you accidentally remove the equation in a white cell, the cell will become red, indicating a change away from the baseline value. You will need to reinstate the linkage back to the Baseline farm sheet, 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. The easiest way to do this is on the Strategy farm sheet, locate the cell which has been deleted, type in an equals (=) sign, then go back to the matching cell on the Baseline farm sheet cell and click in that cell. This should reinstate the equation, repopulating the same number for the Strategy farm as per the Baseline 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 sheet of the newly downloaded file and paste back into your working copy of ADCC.

In the example below (Figure 59), 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.

Milking Cows	Heifers >1 yr age	Heifers <1 yr age
400	75	100

Figure 59. 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 white cell to white text in a red cell.

How are the results of the strategy calculated?

The whole-farm abatement strategy calculations remain the same as the baseline farm system, using the altered inputs to determine changes in GHG emissions. 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 baseline 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 60, 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 baseline 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 CH₄ and N₂O emissions, and pre-farm embedded emissions all declined, while carbon sequestration increased. Net farm GHG emissions declined by ~ 169 t CO₂e/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 \$30/t CO₂e, generated an additional income of \$5,077. When coupled with the savings of \$6,500, total farm benefits increased by \$11,577/annum (Figure 60). Note that it is highly unlikely that changes like this for a farm system, with the exception of planting additional land down to trees, would result in a carbon credit. Thus, the real benefit was the reduction in expenses with milking fewer cows and having less replacement animals.

Economic implications of changing the baseline 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)	\$0.600	
Enter on farm price received for a t CO ₂ e (\$)	\$30.00	
Calculated potential carbon credit (\$ per farm)	\$5,077	
Calculated net expense to implement the strategy (\$ per farm)	-\$6,500	
Benefit as stand alone abatement (\$ per farm)	\$11,577	
Estimated additional milk income (\$ per farm)	\$0	
Estimated total farm benefit from strategy (\$ per farm)	\$11,577	

Figure 60. Screenshot of the key variables (pink section), and changes in economic results when changing a range of aspects of the baseline farm, 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).

8. Resources

Dairy Australia, through Cathy Ashby, have started a ADCC users group which can be accessed through Teams. Contact Cathy at Cathy.Ashby@dairyaustralia.com.au for more information.

General resources not listed below in abatement/mitigation option reviews

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 Land, Water, and Climate website <https://www.dairyaustralia.com.au/land-water-and-climate>

Dairy Australia reducing emissions website <https://www.dairy.com.au/sustainability/reducing-environmental-impact/reducing-emissions>

Dairy Australia Fert\$mart manual <https://www.dairy.com.au/sustainability/reducing-environmental-impact/reducing-emissions>

Fert\$mart Nitrogen Guidelines: Best management practice

[https://www.dairyaustralia.com.au/resource-repository/2021/06/24/fert\\$mart-nitrogen-guidelines--best-management-practice#.YfH1tepBwnl](https://www.dairyaustralia.com.au/resource-repository/2021/06/24/fert$mart-nitrogen-guidelines--best-management-practice#.YfH1tepBwnl)

Fert\$mart Nitrogen Pocket Guide [https://www.dairyaustralia.com.au/resource-repository/2021/06/24/fert\\$mart-nitrogen-pocket-guide#.YfH1ROpBwnl](https://www.dairyaustralia.com.au/resource-repository/2021/06/24/fert$mart-nitrogen-pocket-guide#.YfH1ROpBwnl)

Moss, A. (2020) Database of nutrient content of Australian feed ingredients.

<https://agrifutures.com.au/wp-content/uploads/2020/09/20-078.pdf>

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>
- Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Faluccci 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>
- 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-CO₂ 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>

9. References

- Agriculture Victoria (2022) Greenhouse gas cycles in agriculture. Available at <https://agriculture.vic.gov.au/climate-and-weather/understanding-carbon-and-emissions/greenhouse-gas-cycles-in-agriculture>
- Australian Government (2022) National Inventory Report 2021: 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>
- 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, Eckard 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.
- Cosgrove GP, Koolaard J, Luo D, Burke JL, Pacheco D (2009) The composition of high sugar ryegrasses. *Proceedings of the New Zealand Grassland Association* **71**, 187-193.
- Dairy Australia (2020) Fert\$mart Nitrogen Pocket Guide. Available at [https://www.dairyaustralia.com.au/resource-repository/2021/06/24/fert\\$mart-nitrogen-pocket-guide#.YfH1ROpBwnl](https://www.dairyaustralia.com.au/resource-repository/2021/06/24/fert$mart-nitrogen-pocket-guide#.YfH1ROpBwnl)
- 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/>

- Kyttä V, Roitto M, Astaptsev A, Saarinen M, Tuomisto HI (2022) Review and expert survey of allocation methods used in life cycle assessment of milk and beef. *The International Journal of Life Cycle Assessment* **27**, 191-204.
- Lynch J, Cain M, Pierrehumbert R, Allen M (2020) Demonstrating GWP*: A Means of Reporting Warming-Equivalent Emissions That Captures the Contrasting Impacts of Short- and Long-Lived Climate Pollutants. *Environmental Research Letters* **15**, 044023.
- 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.
- Moate PJ, Williams SRO, Jacobs JL, Hannah MC, Beauchemin KA, Eckard RJ, Wales WJ (2017) Wheat is more potent than corn or barley for dietary mitigation of enteric methane emissions from dairy cows. *Journal of Dairy Science* **100**, 7139-7153.
- Myhre G, Shindell D, Bréon F-M, Collins W, Fuglestedt J, Huang J, Koch D, Lamarque J-F, Lee D, Mendoza B, Nakajima T, Robock A, Stephens G, Takemura T, Zhang H (2013) Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Adapted in https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf
- Ranganathan J, Bhatia P (2004) The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard (Revised Edition). Available at https://www.researchgate.net/publication/258261856_The_Greenhouse_Gas_Protocol_a_Corporate_Accounting_and_Reporting_Standard_Revised_Edition
- Rugoho I, Gourley CJP, Hannah MC (2017) Nutritive characteristics, mineral concentrations and dietary cation-anion differences of feeds used within grazing-based dairy farms in Australia. *Animal Production Science* **57**, 858-876.
- 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.
- Whitehead DC (1995) Grassland nitrogen. (CAB International: Wallingford, UK).

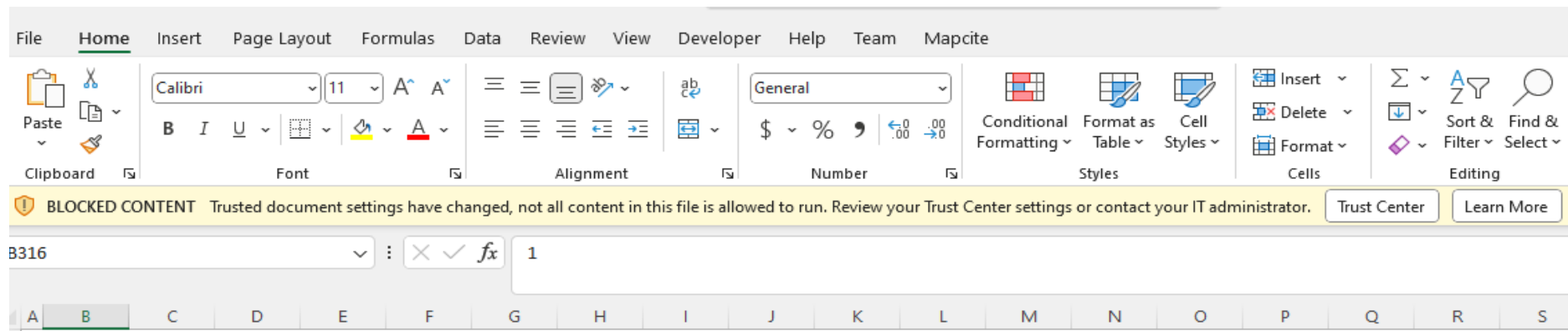
10. Appendices

Appendix 1 Enabling macros instructions

When opening ADCC version 5.2 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.

In order 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.

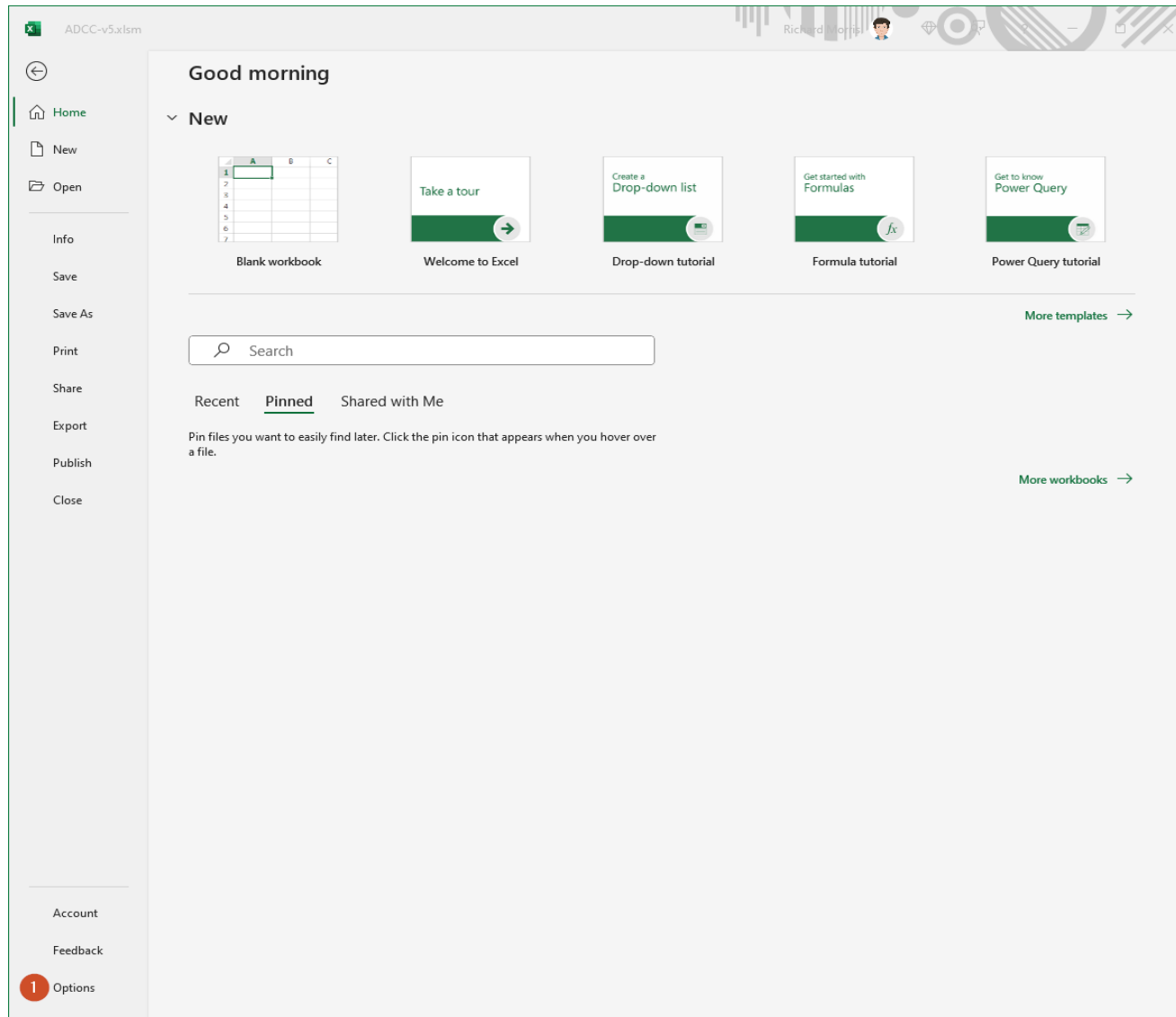
Excel for Windows instructions



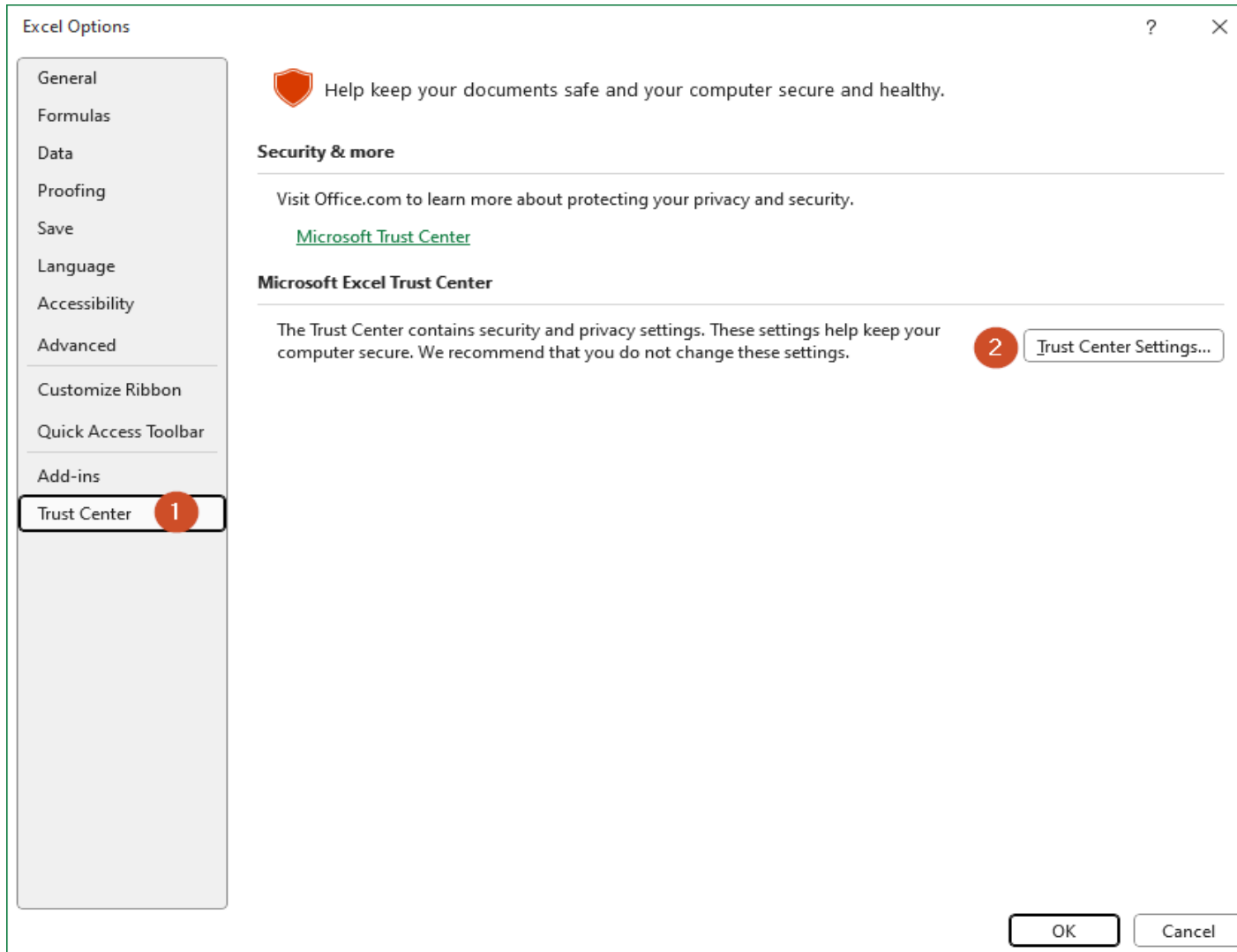
1. If you get the message above, click on the 'Trust Center' button to go straight to the macros security settings options (skip to step 3 below). If you get a red warning similar to the one below, continue onto step 2.



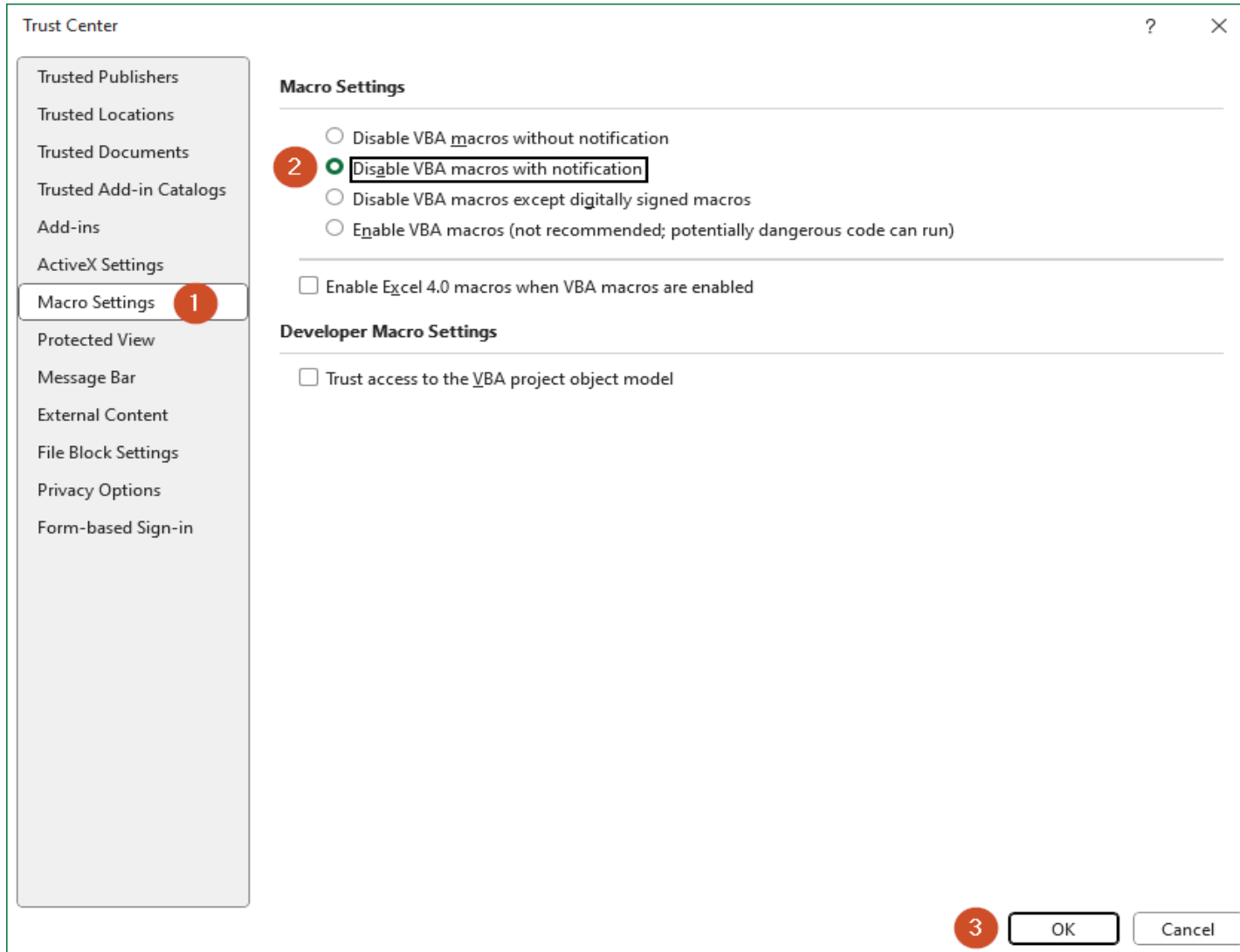
2. Click on the 'File' menu at the top left of the Excel window, then click on the 'Options' button at the bottom left.



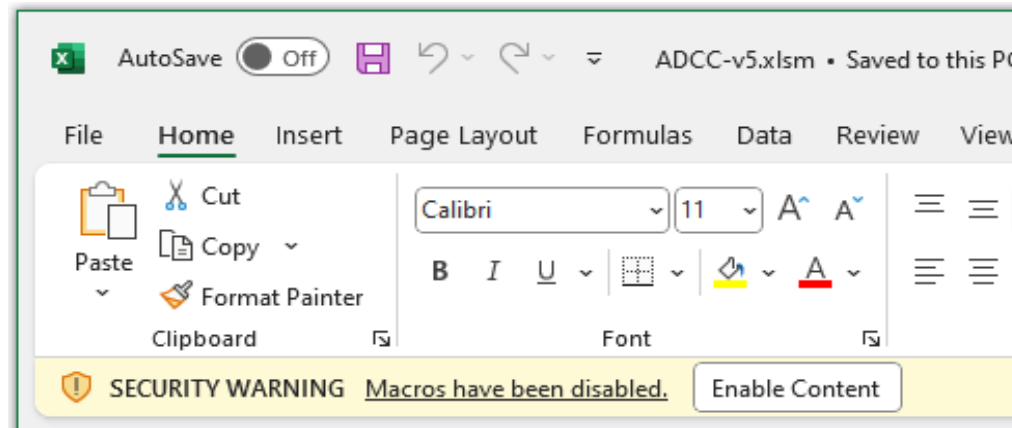
3. Within the Options window, click on the 'Trust Center' option from the left hand side menu (1) and then the 'Trust Center Settings' button on the right hand side.



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.

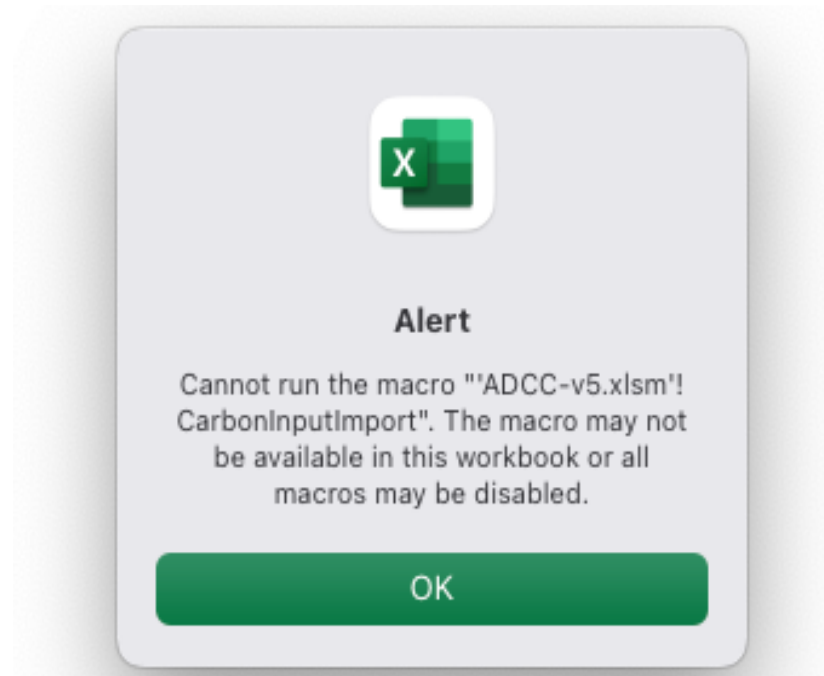


5. Now when a spreadsheet containing a macro opens for the first time, you will be prompted at the top of the window that macros have been disabled, but you need to enable the macros if the spreadsheet is from a trusted source (e.g. Dairy Australia), by clicking on the 'Enable Content' button as shown 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.**

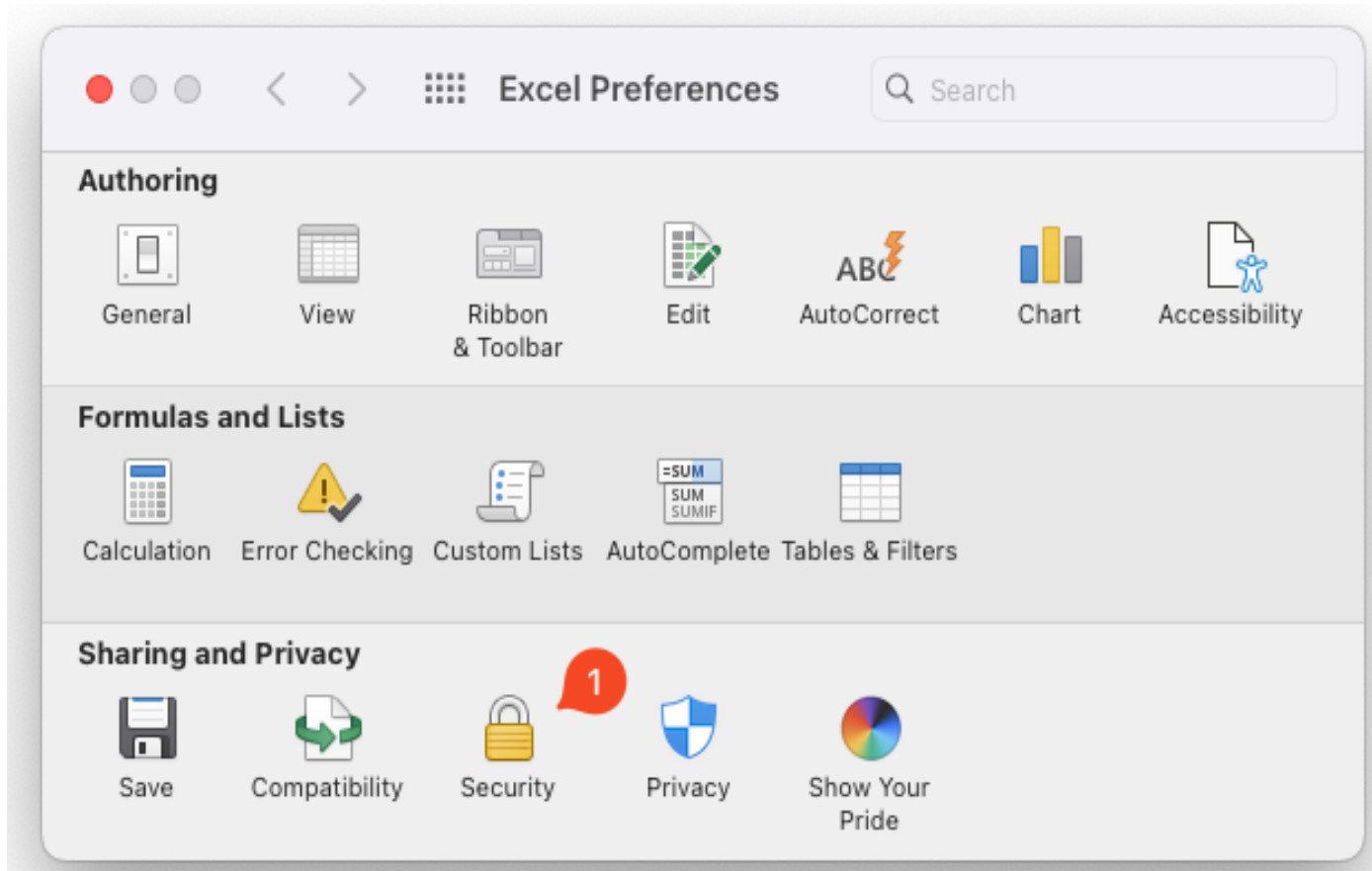


Excel for Mac instructions

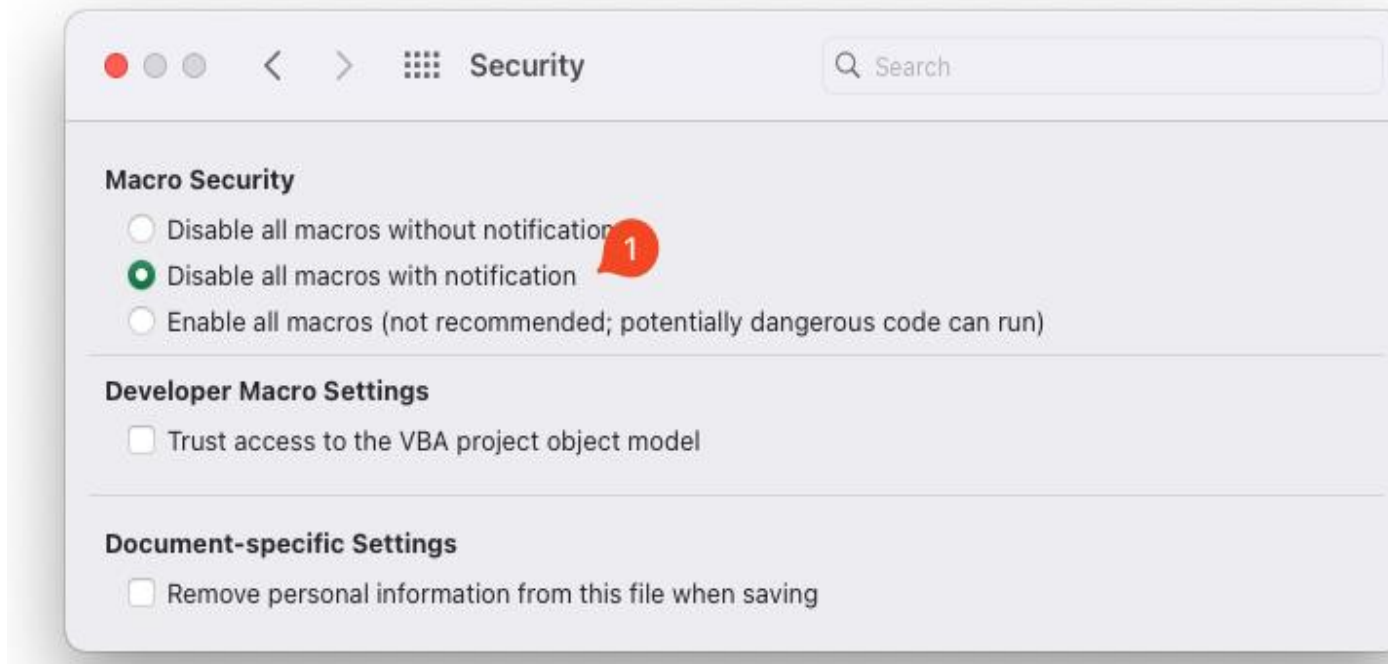
In order to run the macro, the Excel macros security settings must be set correctly. If they are too high, you will get an error message like the one below when you open the spreadsheet.



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).



6. 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](#)

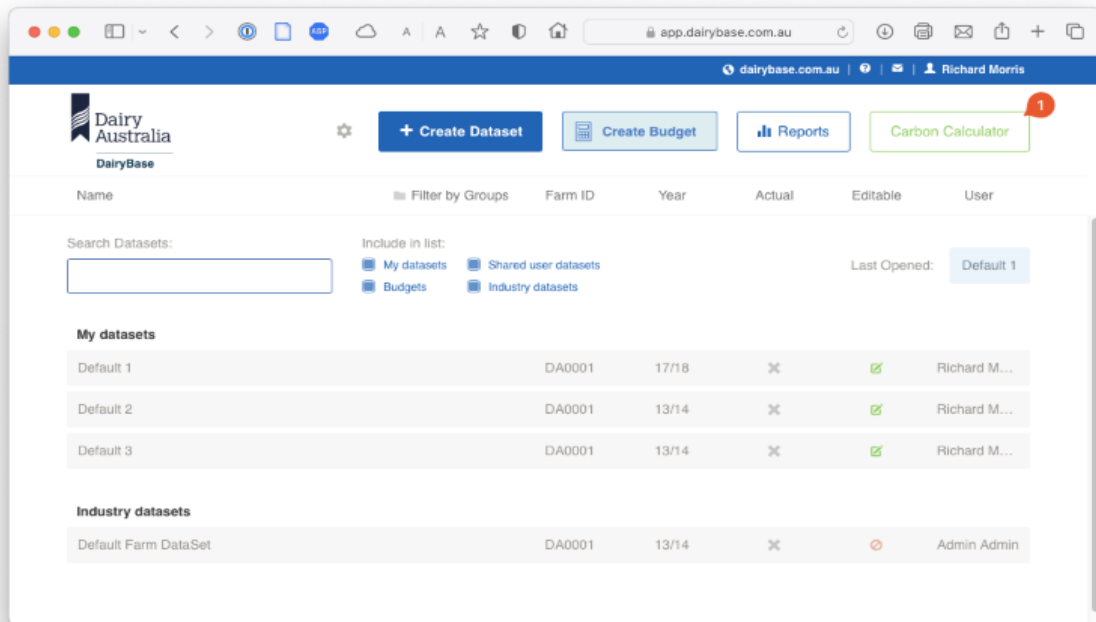
Disable Macros

Enable Macros

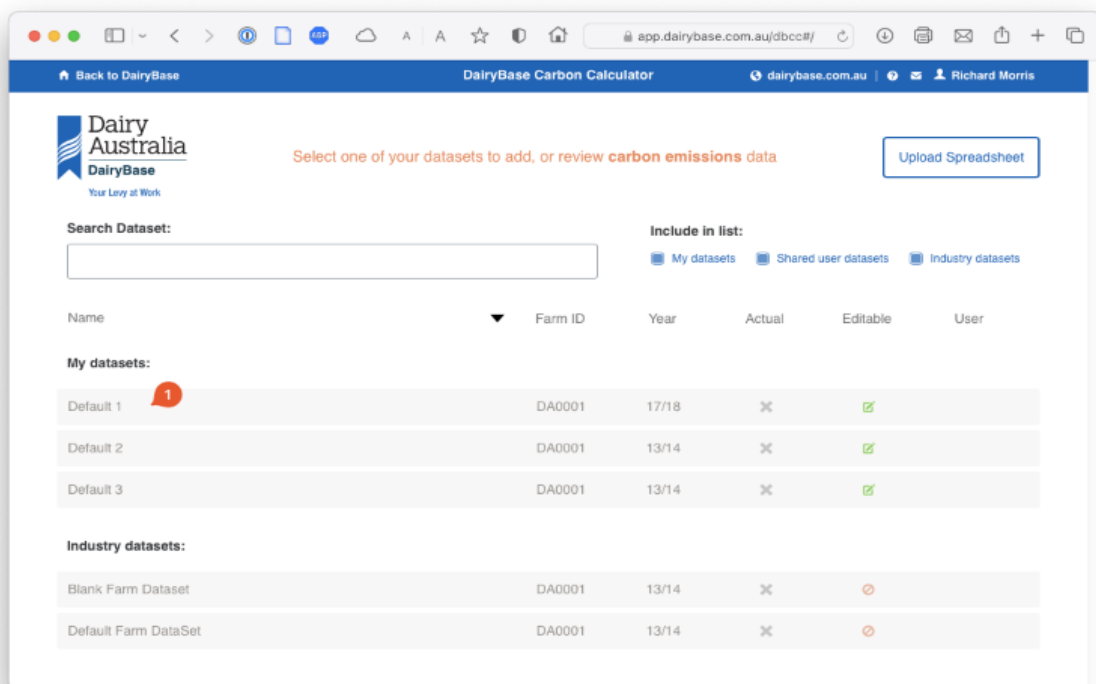
Appendix 2 DairyBase import

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

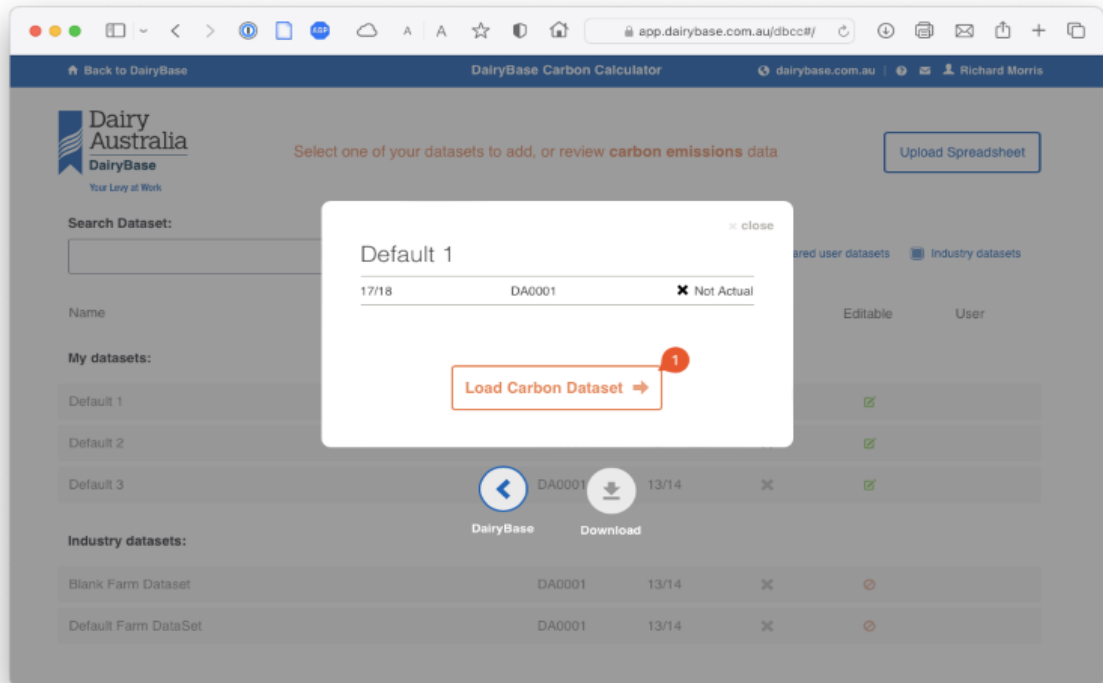
1. Login and then click on the Carbon Calculator button at the top right of the page



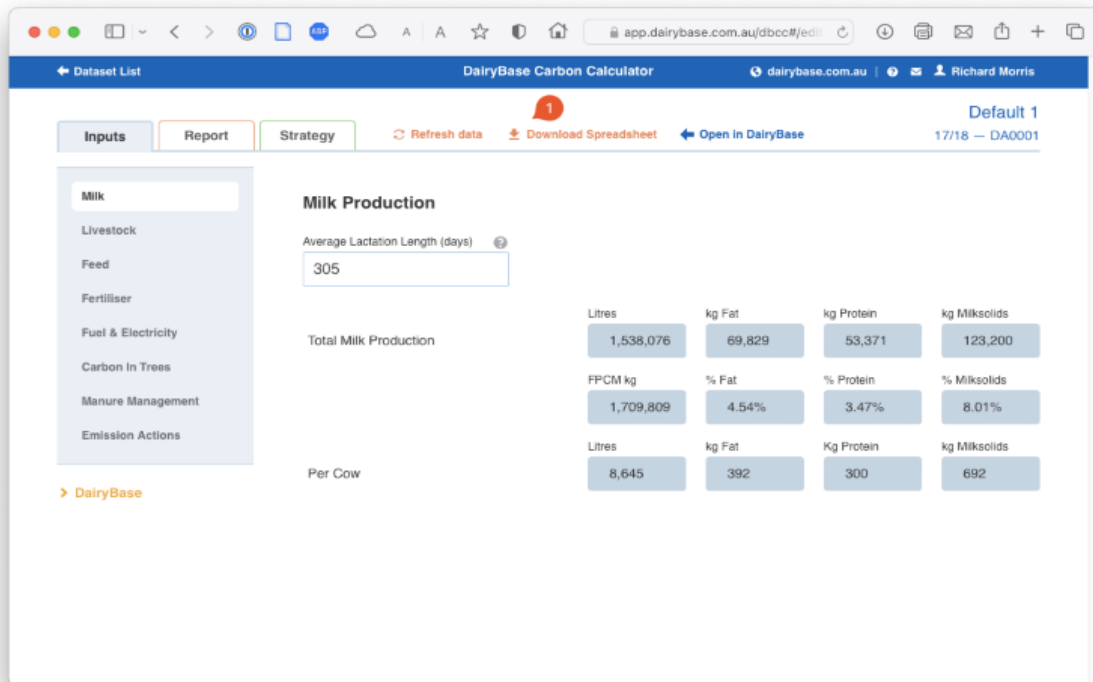
2. Select the dataset you wish to bring into ADCC by clicking on it. In the example below we are wanting to import Default 1.



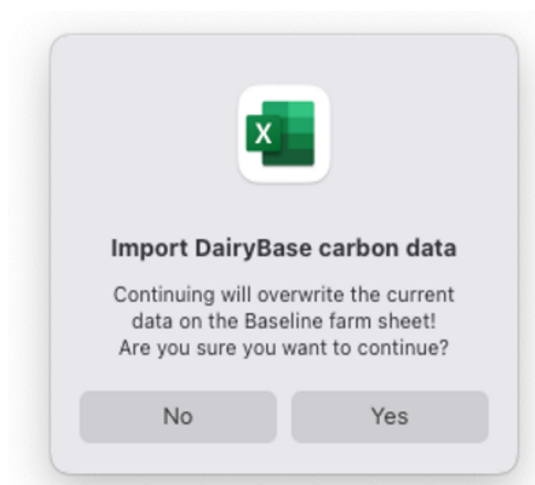
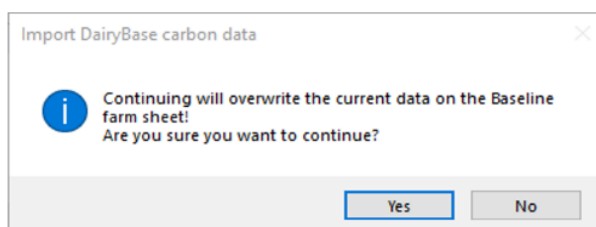
3. Conform you want to load the carbon dataset by clicking on the 'Load Carbon Dataset' button.



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.

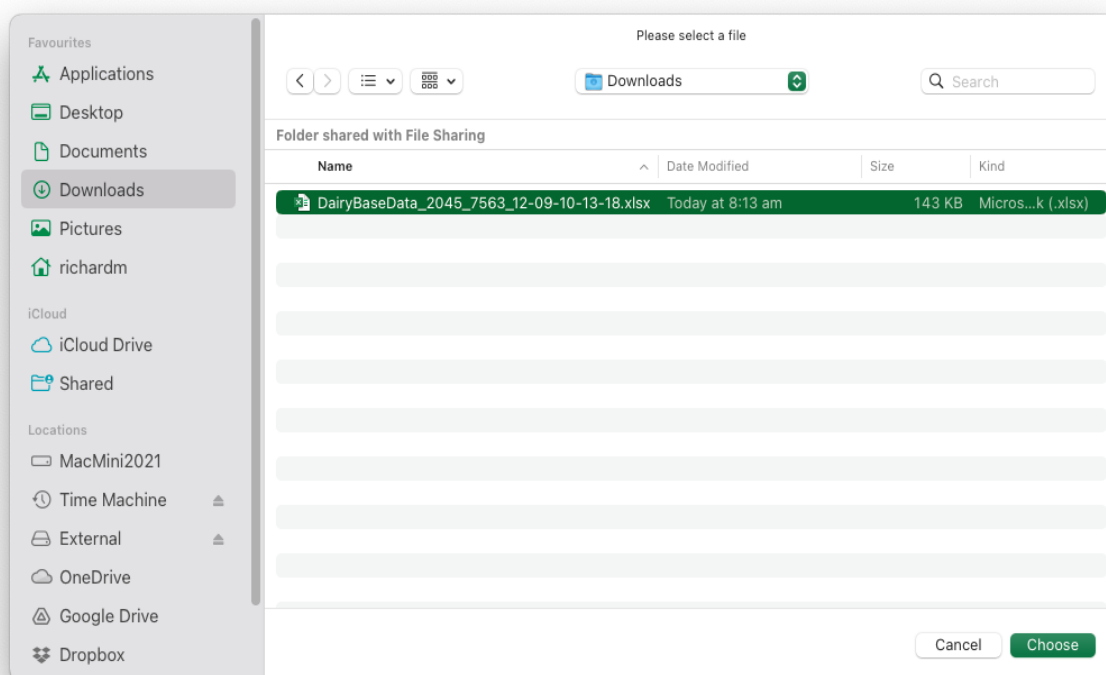
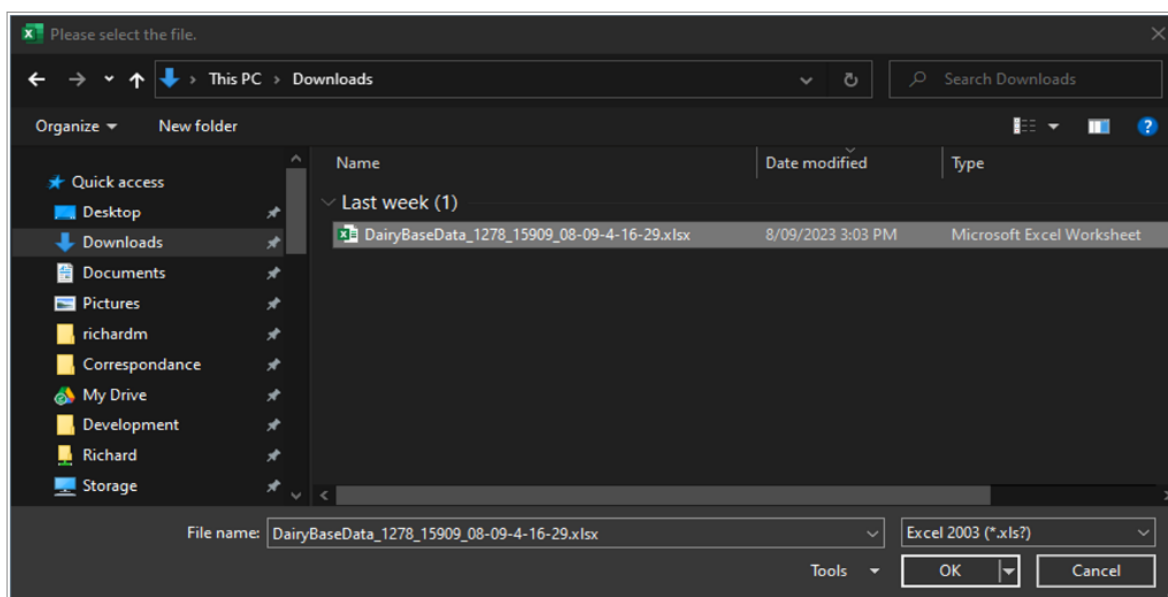


5. The download will be named something like 'DairyBaseData_1278_17774_08-09-4-13.xlsx' which includes a unique user ID (i.e., 1278), unique farm ID (i.e., 17774) and the date and time the file is being downloaded (8th September at 4:13am).
6. Now you have the DairyBase data in a file which can be imported into ADCC by progressing to the Baseline 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 Baseline 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 it 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 baseline 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 baseline 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 four:

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 and pre-farm gate embedded emissions from concentrates to the milk production (348 t CO₂e/annum in this example). This is based on the assumption that most electricity is either consumed in the dairy shed or for irrigating pastures fed to dairy cows. Likewise, most concentrates are fed to the milking herd compared to raising other livestock for the dairy-beef market.

The user defines where to attribute pre-farm gate embedded emissions from purchased fodder. In the previous version of ADCC (version 5.10), we attributed all GHG emissions from purchased fodder to the milking herd. However, for some farms raising all their stock, a proportion of purchased fodder could go to the beef enterprise. In this example, we have retained an assumption that 100% of purchased fodder remains with the dairy enterprise; the default if users do not determine the percentage to the dairy enterprise.

All GHG emissions from the milking herd, replacement heifers and bulls (2,544 t CO₂e/annum in this example) were multiplied by the proportion of total energy to milk, i.e. 88% in this example, thus attributing 2,233 t CO₂e/annum to milk production, with the balance 12% (311 t CO₂e/annum) attributed to meat production to reflect culled cows, sold replacements etc.

All GHG emission from Other Livestock (106 t CO₂e/annum) was attributed to meat production.

General farm emissions (N fertilisers, urea, and lime CO₂e emissions, pre-farm embedded emissions from fertilisers, emission from fuel, and carbon sequestered in trees), totalling 565 t CO₂e/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 477 t CO₂e/annum, with the balance 16% of general farm GHG emissions (88 t CO₂e/annum) attributed to meat production.

Therefore, milk production was allocated 3,059 t CO₂e (i.e. sum of 2,233 t CO₂ from the milking herd related livestock, 176 t CO₂e from electricity, 172 t CO₂e from purchased concentrates and fodder, and 477 t CO₂e from general farm emissions) while meat production was allocated the balance 504 t CO₂e (i.e. sum of 106 t CO₂e from Other livestock, balance of 311 t CO₂e from dairy herd related livestock (culled cows, bulls and replacement heifers no longer retained), and balance of 88 t CO₂e 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 85.9% and 14.1%, 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 ₂ e/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)								176
Milk only emissions (purchased grain + fodder)								172
Meat only emissions (Other livestock)								106
Meat only emissions (purchased fodder)								0
Dairy livestock emissions (milk/meat breakdown)								2,544 (2,233/311)
General farm emissions (milk/meat breakdown)								565 (477/88)

Total emissions								3,563
Total milk GHG emissions								3,059
Total meat GHG emissions								504
% total CO ₂ allocated milk								85.9%
% total CO ₂ allocated meat								14.1%

Step 5:

Milk allocated GHG emissions were then divided by total milk production to estimate the EI for milk production. In this example, 3,059 t CO₂e was divided by 3179.3 t FPCM, resulting in an EI of 0.96 kg CO₂e/kg FPCM. Total meat allocated GHG emissions were then divided by total meat produced to estimate the EI of meat production. In this example, 504 t CO₂e was divided by 132.475 t liveweight, for an EI of 3.81 kg CO₂e/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 CO₂ allocated to cull cows was 2,544 t CO₂e x (1-88%) x 72% + 565 t CO₂e x (1-84%) x 54%, equivalent to 271 t CO₂e. This was then converted into kg of CO₂e, and then divided by total kg of meat from cull cows and bulls (65,650 kg), to estimate an EI of 4.1 kg CO₂e/kg LW. The same process is undertaken for all other stock classes. For this example, the EI was 4.1 kg CO₂e/kg LW for weaned calves, 3.0 kg CO₂e/kg LW for fattened dairy livestock, and 3.2 kg CO₂e/kg LW for fattened Other livestock. This illustrates that while the overall meat EI was 3.8 kg CO₂e/kg LW, there was variation between stock classes. The total GHG emissions to milk production is also divided by total milksolids production to estimate a milksolids EI for ADCC.

	Total emissions (t CO ₂ e/annum)	Total product (t FPCM)	EI milk (kg CO ₂ e/kg FPCM)	Total product (t LW)	EI meat (kg CO ₂ e/kg LW)
Milk	3,059	3,179.3	0.96		
Meat	504			132.5	3.8
Culled cows	271			63.3	4.1
Calves at birth	0			0	0
Calves weaned	93			22.6	4.1
Fattened dairy livestock	13			6.7	3.0
Fattened other livestock	127			40	3.2

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 and Queensland Dairy Accounting Scheme from 2015-16 to 2021-22). Note that with the upgrade of ADCC/DairyBase with respect to tree carbon sequestration, we were unable to generate a percentage of net emissions attributed to carbon sequestered in trees.

Source/sink GHG emissions	Australia-wide	Victoria	VIC-Gippsland	VIC-Northern	VIC-South West	New South Wales	NSW-North	NSW-South
Enteric CH ₄	60%	60%	60%	61%	58%	58%	56%	59%
Waste CH ₄	9%	10%	10%	10%	9%	10%	9%	11%
N ₂ O direct grazing	3%	3%	3%	3%	3%	3%	3%	3%
N ₂ O Manure storage & spread	1%	1%	1%	1%	1%	1%	1%	1%
N ₂ O Indirect N waste	2%	2%	2%	1%	2%	2%	2%	2%
N ₂ O Direct N fertiliser	3%	3%	3%	3%	3%	3%	3%	3%
N ₂ O Indirect N fertiliser	2%	2%	2%	1%	2%	2%	2%	1%
Electricity	4%	5%	4%	5%	5%	6%	7%	5%
Fuel	2%	2%	1%	2%	2%	2%	2%	2%
Urea & Lime	2%	2%	2%	1%	2%	2%	2%	1%
Concentrates	5%	5%	5%	5%	5%	5%	5%	6%
Fodder	1%	1%	1%	3%	1%	1%	1%	2%
Fertiliser	5%	5%	6%	3%	6%	5%	6%	4%
Trees	0%	0%	0%	0%	0%	0%	0%	0%

Appendix 4 cont.

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 and Queensland Dairy Accounting Scheme from 2015-16 to 2021-22). Note that with the upgrade of ADCC/DairyBase with respect to tree carbon sequestration, we were unable to generate a percentage of net emissions attributed to carbon sequestered in trees.

Source/sink GHG emissions	Queensland	QLD-North	QLD-South	South Australia	Tasmania	Western Australia	Low grain ¹	Med grain ¹	High grain ¹
Enteric CH ₄	60%	61%	60%	61%	66%	60%	64%	60%	59%
Waste CH ₄	9%	9%	9%	10%	8%	8%	9%	9%	9%
N ₂ O direct grazing	3%	3%	3%	3%	4%	3%	4%	3%	3%
N ₂ O Manure storage & spread	1%	1%	1%	1%	1%	1%	1%	1%	1%
N ₂ O Indirect N waste	2%	2%	2%	2%	2%	2%	2%	2%	2%
N ₂ O Direct N fertiliser	3%	4%	3%	3%	4%	3%	4%	3%	3%
N ₂ O Indirect N fertiliser	1%	1%	1%	1%	2%	2%	1%	2%	1%
Electricity	4%	4%	4%	3%	1%	3%	3%	5%	4%
Fuel	2%	2%	2%	3%	1%	2%	2%	2%	2%
Urea & Lime	2%	2%	1%	1%	2%	2%	2%	2%	1%
Concentrates	6%	5%	6%	5%	4%	6%	3%	4%	6%
Fodder	1%	1%	1%	2%	1%	1%	1%	1%	1%
Fertiliser	5%	5%	4%	5%	6%	6%	5%	6%	5%
Trees	0%	0%	0%	0%	0%	0%	0%	0%	0%

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.

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 2015-16 to 2021-22). Note that with the upgrade of ADCC/DairyBase with respect to tree carbon sequestration, we were unable to generate a percentage of net emissions attributed to carbon sequestered in trees.

Source/sink GHG emissions	Australia-wide	Victoria	VIC-Gippsland	VIC-Northern	VIC-South West	New South Wales	NSW-North	NSW-South
Milk EI	0.94	0.93	0.94	0.89	0.95	0.99	1.04	0.94
Meat EI	4.36	4.36	4.56	4.09	4.43	4.41	4.57	4.24
Milk MS EI	11.26	11.37	11.45	11.00	11.68	12.09	12.58	11.54
Enteric methane	0.57	0.55	0.56	0.54	0.55	0.57	0.59	0.56
Waste methane	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10
N2O direct grazing	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Manure storage & spread	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Indirect N waste	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.01
Direct N fertiliser	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Indirect N fert	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01
Electricity	0.03	0.04	0.04	0.05	0.05	0.06	0.07	0.04
Fuel	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02
Urea & Lime	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.01
Concs	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05
Fodder	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.02
Fertiliser	0.05	0.05	0.06	0.03	0.06	0.05	0.06	0.04
Milk to meat ratio	0.86	0.88	0.88	0.89	0.88	0.86	0.86	0.87
Meat to milk ratio	0.14	0.12	0.12	0.11	0.12	0.14	0.14	0.13

Appendix 4 cont.

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 2015-16 to 2021-22). Note that with the upgrade of ADCC/DairyBase with respect to tree carbon sequestration, we were unable to generate a percentage of net emissions attributed to carbon sequestered in trees.

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	1.02	1.06	1.02	0.88	0.87	0.92	0.94	0.93	0.93
Meat EI	4.47	4.68	4.42	4.11	4.40	4.21	4.86	4.38	4.20
Milk MS EI	11.13	11.23	11.11	10.87	10.38	10.88	11.23	11.28	11.34
Enteric methane	0.62	0.64	0.61	0.54	0.57	0.56	0.60	0.56	0.55
Waste methane	0.10	0.09	0.10	0.08	0.07	0.08	0.09	0.09	0.09
N2O direct grazing	0.03	0.04	0.03	0.03	0.03	0.03	0.04	0.03	0.03
Manure storage & spread	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Indirect N waste	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02
Direct N fertiliser	0.03	0.04	0.03	0.03	0.03	0.03	0.04	0.03	0.03
Indirect N fertiliser	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01
Electricity	0.04	0.04	0.04	0.03	0.01	0.03	0.02	0.04	0.04
Fuel	0.02	0.02	0.02	0.03	0.01	0.02	0.02	0.02	0.02
Urea & Lime	0.02	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01
Concs	0.06	0.06	0.06	0.04	0.03	0.05	0.02	0.04	0.05
Fodder	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Fertiliser	0.05	0.05	0.05	0.04	0.05	0.06	0.05	0.05	0.05
Milk to meat ratio	0.88	0.85	0.89	0.88	0.87	0.83	0.86	0.87	0.87
Meat to milk ratio	0.12	0.15	0.11	0.12	0.13	0.17	0.14	0.13	0.13

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.