Australian Dairy Carbon Calculator

Manual

Version 5

Section 7 only - COST

November 2022

A herd of cows in a field

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Logo, company name

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## Acknowledgements

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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.

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

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Table of Contents

[Acknowledgements 2](#_Toc117073143)

[1. Australian Dairy Carbon Calculator Manual 4](#_Toc117073144)

[2. Glossary and commonly used acronyms 5](#_Toc117073145)

[7. Abatement options (Carbon Offset Scenario Tool) 10](#_Toc117073146)

[7.1. Enteric methane reduction through breeding or management 15](#_Toc117073147)

[7.2. Extended lactation to reduce enteric methane production 17](#_Toc117073148)

[7.3. Extended longevity to reduce replacement rates 20](#_Toc117073149)

[7.4. Replacing supplements in the diet with a source of dietary fats/oils 22](#_Toc117073150)

[7.5. Increase diet supplementation with a source of dietary fats/oils 25](#_Toc117073151)

[7.6. Improved diet digestibility to protein ratio through management 28](#_Toc117073152)

[7.7. Improved diet digestibility to protein ratio through supplementary feed 30](#_Toc117073153)

[7.8. Coating of N fertiliser with an N inhibitor 32](#_Toc117073154)

[7.9. Applying N inhibitors to urine patches 35](#_Toc117073155)

[7.10. Whole-farm abatement strategy 37](#_Toc117073156)

[8. Resources 40](#_Toc117073157)

[9. References 42](#_Toc117073158)

# 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 only contains the GHG adaptation options explored in the Carbon Offset Scenario Tool (section 7), along with the Glossary and commonly used acronyms (section 2), full listing of resources and appropriate references (sections 8 and 9). If you wish to access all or some of the other sections of the ADCC manual, you can find these on the Dairy Australia website. Note the Table and Figure numbers in this section match those of the full manual; they have not recommenced as Table or Figure 1.

# Glossary and commonly used acronyms

|  |  |
| --- | --- |
|  |  |
| 3-NOP | 3-nitrooxypropanol trading as Bovaer® |
| Abatement | Strategy to reduce net GHG emissions |
| ADCC | Australian Dairy Carbon Calculator |
| Allocation | Dairy farms produce milk and meat. ADCC allocates net GHG emissions, based on an energy allocation method, to milk and meat |
| Anthropogenic | GHG emissions caused or influenced by people, either directly or indirectly |
| AR4 | IPCC Fourth Assessment Report |
| AR5 | IPCC Fifth Assessment Report |
| Benchmarking | Comparing the performance of the enterprise against the rest of the industry |
| Carbon accounting | The process used to qualify greenhouse gas (GHG) emissions of an enterprise |
| Carbon flux | The change in carbon stocks stored in sinks over a duration, usually a yearly basis |
| Carbon footprint | Quantification of the GHG emissions emitted directly or indirectly by an individual, company, or product |
| Carbon negative/carbon positive | Condition in which net carbon dioxide equivalent emissions are negative and positive, respectively. However, these terms can be ambiguous and are sometimes used inconsistently. Therefore, the dairy industry is moving away from the use of these terms and referring to a farm as remaining either an emitter of emissions (i.e. has not attained carbon neutrality/net zero), as net zero (all emissions offset by carbon sequestration), or a beyond net zero (sequestering more carbon than emitting) |
| Carbon neutrality | Net-zero GHG emissions |
| Carbon sequestration | The process whereby carbon dioxide is removed from the atmosphere and stored in carbon sinks such as soils and vegetation |
| Carbon sink | A reservoir that absorbs carbon dioxide from the atmosphere. Natural carbon sinks include plants, soils, and oceans |
| Carbon stocks | Carbon stocks refers to the quantity of carbon that has been sequestered from the atmosphere and is stored in a carbon sink |
| CFI | Carbon Farming Initiative; the original Federal government voluntary carbon credit scheme, later replaced with the ERF and subsequently the CSF |
| CH4 | Methane |
| CO2 | Carbon dioxide |
| CO2e | Carbon dioxide equivalents (CO2e) are a unit used to compare emissions from different GHGs based on their global warming potential (GWP) over a specific timeframe, typically 100 years (GWP100) |
| COST | Carbon Offset Scenario Tool, a series of mitigation options embedded within ADCC |
| CP | Crude protein |
| CSF | Climate Solutions Fund; the Australian Government’s most recent 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 N2O) |
| 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 |
| 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 (CO2), methane (CH4), and nitrous oxide (N2O) |
| Global temperature potential | Global Temperature Potential (GTP) is an alternative to GWP100 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 |
| 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 (CH4) 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 CH4) and with manure management (waste CH4) |
| N | Nitrogen |
| Net emissions | Total GHG emissions minus carbon sequestered in carbon sinks (trees and/or soils) |
| NGGI | The National GHG Inventory accounts for, and estimates, Australia’s GHG emissions and sinks |
| NGER | National Greenhouse and Energy Reporting |
| NH4 | Ammonium |
| Nitrous oxide | Nitrous oxide (N2O) is a GHG that is 265 times more potent than carbon dioxide, based on the IPCC AR5 report. N2O 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 |

# 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 32) 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 emissions,
2. Diet manipulation to reduce enteric CH4 or N2O emissions,
3. Feedbase management to reduce N2O emissions, and
4. Whole farm abatement to reduce CO2, CH4 and/or N2O emissions.

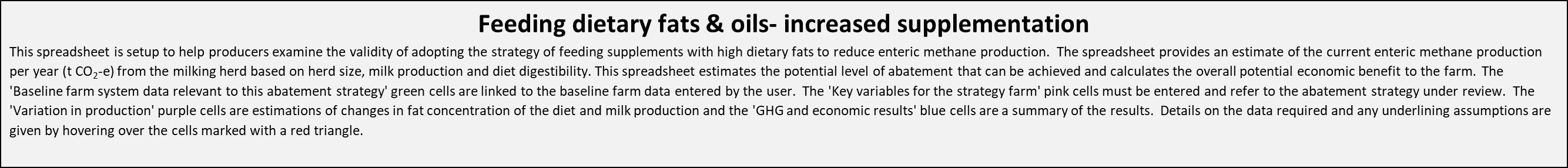
Within ADCC, each green box is hyperlinked to the appropriate abatement option. For example, clicking on the Extended lactation box takes the user to the Extended lactation abatement option. Alternatively, you may wish to explore multiple aspects of the farm system, or an abatement option that is not 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.

Diagram

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**Figure 32.** 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 33). For example, *Reducing enteric methane emissions through breeding or management* explores options that will focus on reducing enteric CH4 emissions. Examples include breeding animals with a lower enteric CH4 emissions per unit of feed intake or the inclusion of a management option 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 33 illustrates the explanation of feeding of dietary fats and oils, through increased supplementation.



**Figure 33.** 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 34). 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 6.2 for more information specific to Extended lactations).

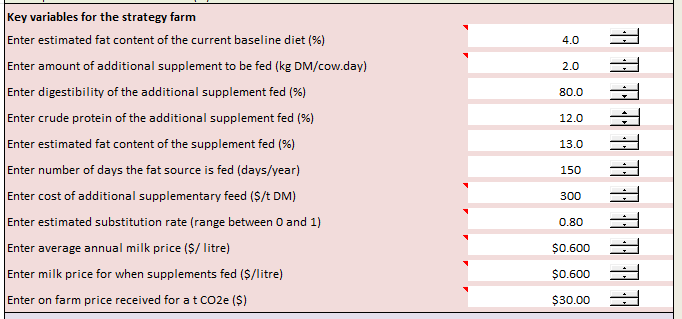
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**Figure 34.** Screenshot of the green box illustrating some key baseline farm data related to the “Increase diet supplementation with a source of dietary fats/oils” abatement option.

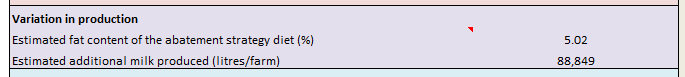
Next is a pink box with **Key variables for the strategy farm** (Figure 35). These are a series of questions specific to the abatement strategy being explored. The cells needing data are all coloured white and contain up/down arrows to select the most relevant answer to the question asked. For example, in Figure 35, 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.

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.



**Figure 35.** 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 36). 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 36, 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 an combination of both, so that the overall diet fat content decreases below 7%. In Figure 36, 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.

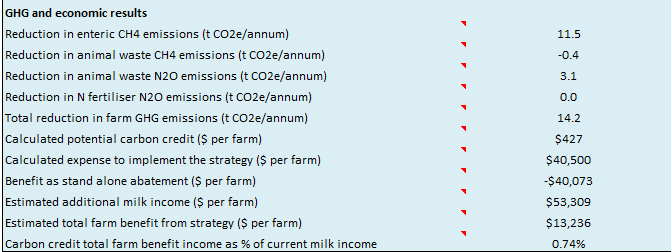


**Figure 36.** Screenshot of the purple box illustrating the fat content and change in milk production with the “Increase diet supplementation with a source of dietary fats/oils” abatement option.

The last blue box contains **GHG and economic results** (Figure 37). 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.

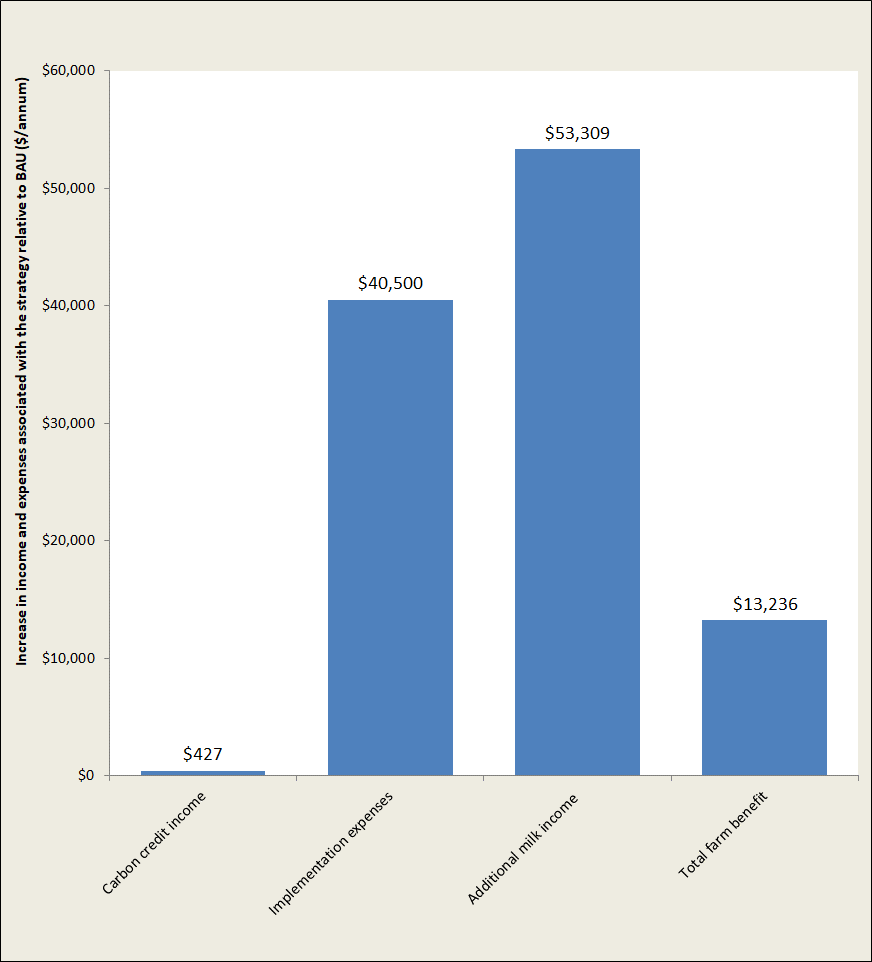
Each result has a note with information related to the result, as indicated by the red triangle in the top right corner of each result description. A negative reduction in GHG emissions reflects an increase in GHG emissions. For example, in Figure 37 while enteric CH4 emissions declined by 11.5 t CO2e/annum, 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.



**Figure 37.** 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 38), 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 6.7 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 38.** Screenshot of the results of an abatement strategy to reduce enteric methane production through the feeding of dietary fats & oils. The strategy generated $427 in carbon credits, cost $40,500/annum to implement, and increased income from milk production by $53,309/annum, thus total farm benefit was $13,236/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.

## Enteric methane reduction through breeding or management

This strategy explores options to reduce enteric CH4 emissions through breeding or herd management. For example, animals with lower 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*®). 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 6.4 or 6.5 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*

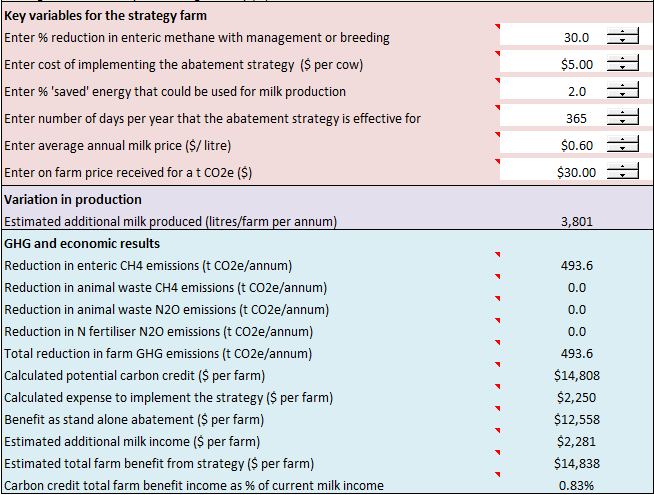
There are several questions in the pink key variables section to determine the percentage reduction in enteric CH4 with implementation, the cost of implementation, any potential increase in milk production, the duration the intervention is effective, the average annual milk price, and on-farm price received for a tonne of CO2e (Figure 39).

*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 x (1-30% reduction potential) x (365 days effective/ 365 days of the year)).

*Example of results*

In the example below (Figure 39), a vaccine that reduced CH4 emissions by 30%, is administered to each milking cow every year, and remaining effective for the full 12 months. The vaccine costs $5/milker (price is unknown at the time of publishing this manual so an indicative price is included here), resulting in a 2% increase in milk production. Much of these numbers will need to be based on scientific literature, advice from the supplier of the additive/vaccine, or how the cows performed compared to previously. 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 3,801 litres of milk per annum. Implementation of the strategy reduced total farm GHG emissions by 493.6 t CO2e/annum. The annum total farm benefit was $14,838, based on a carbon credit of $14,808, an additional milk income of $2,281 and an implementation cost of $2,250 (Figure 39).



**Figure 39.** 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 breeding or management (blue section).

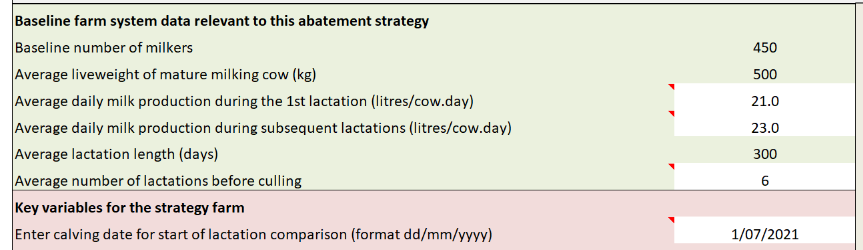
## Extended lactation to reduce enteric methane production

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 40). 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.



**Figure 40.** 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 41).

*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\_DGAS), 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 41), 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 41).

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).

Table

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**Figure 41.** 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).

## 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 42).

*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 42), 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 42). 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 42).

Graphical user interface, text, application

Description automatically generated

**Figure 42.** 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.

## 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 6.5).

*Key variables for the strategy farm*

There are many questions in the pink key variables section to ascertain (Figure 43). 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 43).

*How are the results of the strategy calculated?*

The feeding of dietary fats is currently 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>), although at the time of developing this manual, the ERF project required updating with the current NGGI methodology.

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 x dietary fat % of the overall diet (Moate *et al.* 2011). Changes in the diet’s energy content are considered to estimate any additional energy available for milk production, assuming 5.5 MJ of metabolisable energy 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 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 43), 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 43). The high-fat supplement was higher in DMD (80% vs 72% for the silage), thus milk production increased by ~ 58,000 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 32.6 t CO2e/annum. Total farm benefit was $22,322, based on a carbon credit of $978, an additional milk income of $34,843, and an implementation cost of $13,500 (Figure 43).

Table

Description automatically generated with low confidence

**Figure 43.** 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.

## 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 6.4) 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 44). 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 44).

*How are the results of the strategy calculated?*

Unlike the previous section 6.4, 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 per litre of milk.

This strategy does not follow the same guidelines as the ERF/CSF methodology as shown in section 6.4. 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 44), 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 ~ 88,850 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 14.2 t CO2e/annum, mainly 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 $13,236, based on a carbon credit of $427, an additional milk income of $53,309, and an implementation cost of $40,500 (Figure 44).

Table

Description automatically generated

**Figure 44.** 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.

## 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 6.7 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 45). 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 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 45), 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 24.7 t CO2e/annum. Total farm benefit was $140,130, based on a carbon credit of $740, an additional milk income of $144,390, and an implementation cost of $5,000 (Figure 45).

Table

Description automatically generated

**Figure 45.** 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.

## 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 6.6 explored other management options to improve the DMD to CP ratio of the diet, whereas sections 6.4 and 6.5 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 46).

*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 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 46), 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. 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 slightly 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 4.4 t CO2e/annum. Total farm benefit was -$5,880 based on a carbon credit of $131, an additional milk income of $14,239, and an implementation cost of $20,250 (Figure 46)

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%.

Graphical user interface, table

Description automatically generated with medium confidence

**Figure 46.** 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.

## 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 N2O emissions. Nitrification inhibitors work by retaining fertiliser N in the ammonium (NH4) form for longer, slowing down the denitrification process where NH4 converts into nitrate (NO3), and subsequently into 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 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 N2O losses by 10%, reduce the amount of N fertiliser applied by 10%, so the N retained in the NH4 form can be taken up by the pastures as opposed to converting into NO3 and N2O 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 N2O 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 CO2e (Figure 47). 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 N2O loss, and the inhibitor’s efficacy in reducing N2O losses. The direct and indirect N2O 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 N2O 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/kg DM, to determine the change in milk production. This will then also alter daily intake and enteric CH4 emissions. Changes in waste CH4 and N2O 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 47), 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 47).

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).

Table

Description automatically generated with medium confidence

**Figure 47.** 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.

## 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 6.8), 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 48). 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 48), we assumed the cows spent 85% of their time grazing pasture (balance in laneways, 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 48). Total farm benefit was -$1,526, based on a carbon credit of $724, and an implementation cost of $2,250. The cost of implementation was greater than the reduction in N2O loss, based on the assumptions used here. 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.

Table

Description automatically generated with medium confidence

**Figure 48.** 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.

## 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, average age of the trees and amount of carbon sequestered/ha using other tools 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 back 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 49). 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. Th easiest way to do this is on the Strategy farm sheet, located 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 49), 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.

A picture containing text

Description automatically generated

**Figure 49.** 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.

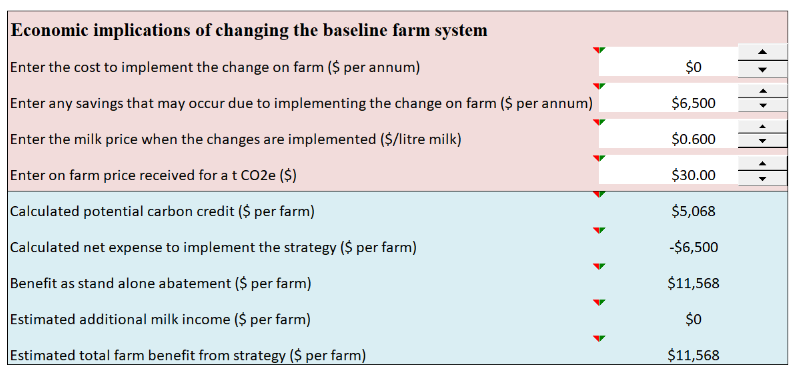
*How are the results of the strategy calculated?*

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 50, 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 by 5ha to 20ha. All other aspects remained the same (i.e. no change to electricity and fuel consumption or altered fertiliser inputs). The reduction in grain feeding and lower animal herd costs (i.e. lower AI costs, herd health costs) meant the farmer was now saving $6,500/annum. However, the reduction in calves sold post-weaning would erode much of these savings, potentially resulting in a new cost of implementing this strategy. 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 $5,068. When coupled with the savings of $6,500, total farm benefits increased by $11,568/annum (Figure 50).



**Figure 50.** 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).

# Resources

*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#.YfH1tepBwnI>

Fert$mart Nitrogen Pocket Guide <https://www.dairyaustralia.com.au/resource-repository/2021/06/24/fert$mart-nitrogen-pocket-guide#.YfH1ROpBwnI>

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, Falcucci A, Tempio G (2013) Tackling climate change through livestock- A global assessment of emissions and mitigation opportunities. (Food and Agriculture Organization of the United Nations (FAO): Rome, Italy). <https://www.fao.org/3/a0701e/a0701e.pdf>

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

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>

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

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

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.

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.

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