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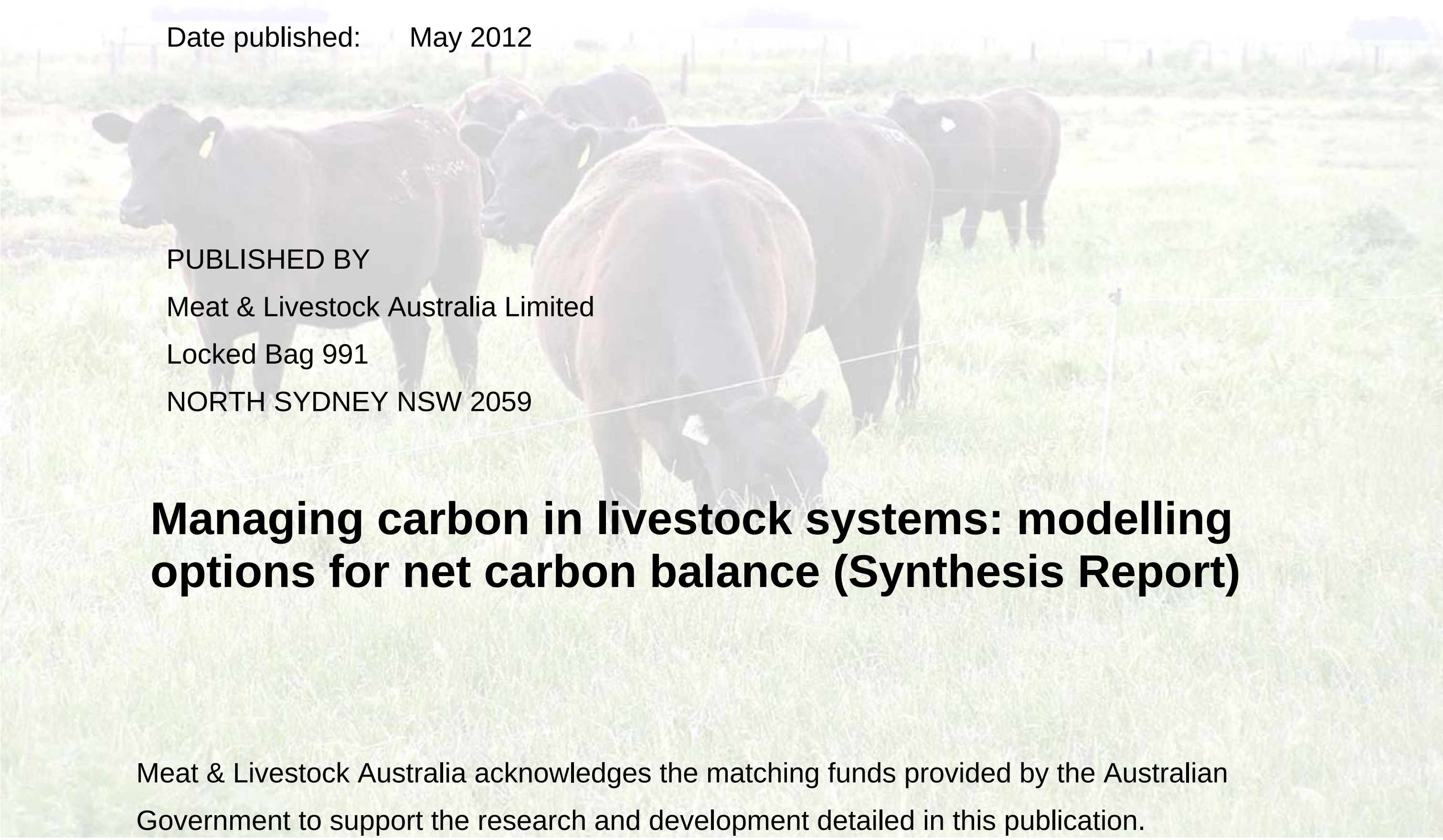

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Managing carbon in livestock systems: modelling options for net carbon balance (Synthesis Report)

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Abstract

CFI methodologies for reducing CO_2-e from methane and nitrous oxide and for storing soil carbon require a standardised, simple to use and consistent (accurate) protocol upon which to base the accounting method.

In the RELRP program six demonstration sites were established to measure or estimate aspects of livestock production systems that should reasonably be expected to contribute data to a carbon balance sheet for each site. These sites covered different geographical regions and production systems. Different processes for collecting on-ground data were used, some measured inputs and outputs required for modelling, others used historical data provided by producers or the state agency responsible for the site / district in which the site was located.

At the two sites where measured, methane emissions approximated modelled estimates. At the one site where measured Nitrous Oxide emissions were less than those predicted by a model.

Where calculation methods were compared side by side at the same site, there were model differences in methane and nitrous oxide emissions. Where the biophysical models and FarmGas calculator were compared side by side they provided similar estimates of methane emissions.

The data requirements for the biophysical models were extensive. Even for the calculators, the assumptions made, based on historical data, were extensive and unlikely to be challenged based on data collected on farm.

We recommend that a simple emissions calculator be developed, based on sensitivity analysis of the factors affecting on-farm greenhouse gas emissions. We also recommend that data on methane and nitrous oxide emissions over a range of enterprises be measured along with sufficient data to enable biophysical models to be run. This would provide the confidence that modelled / calculated estimates were related to observed rates of emission and underpin the development of future accounting systems.

Executive Summary

CFI methodologies for reducing CO_2-e from methane and nitrous oxide and for storing soil carbon require a standardised, simple to use and consistent (accurate) protocol upon which to base the accounting method.

In the RELRP program a number of demonstration sites were established to measure or estimate aspects of livestock production systems that should reasonably be expected to contribute data to a carbon balance sheet for each site. Six sites covering different geographical regions and production systems were chosen. Different processes for collecting on-ground data were used, some measured inputs and outputs required for modelling, others used historical data provided by producers or the state agency responsible for the site / district in which the site was located.

This report focuses on analysis of different models and synthesis of model outcomes over a range of livestock production systems in the different environments covered by the RELRP demonstration sites.

Only two sites (Lansdown in QLD, beef cattle and Armidale in NSW, sheep) measured methane emissions by groups of animals and collected sufficient data to enable the calculation of emissions using models or basic relationship between feed intake and methane emissions. Despite the limited period over which direct measurements were made, there was reasonable agreement between measured and modelled / calculated emissions of methane. It was possible to obtain similar estimates of methane emissions by using animal weight and weigh gain compared to estimates generated by complex models requiring detailed information on soils, weather, pastures and animals.

Within site comparisons using different modelling techniques indicated there were systematic differences between modelling / calculation packages. Within the Tasmanian site, there were marked differences in methane (1.3-1.7 fold) and nitrous oxide (2.8-4.7 fold) emissions depending on the model / calculator (FarmGas v’s Framework Calculator). At the Armidale site, the estimates from FarmGas, SGS, and GrassGro for methane emissions were similar (albeit SGS was slightly lower) and these estimates were within the range recorded by direct measurement of methane emissions using FTIR.

It is not yet clear why the different models differed in Nitrous Oxide emissions. In the one site where N_2O emissions were measured (Armidale), the measured value was considerably lower than that estimated using the SGS Pasture Model. Variability in modelled N_2O emissions is of concern in itself, but also because it was reported that at the Struan site (or modelled data there from) a significant part of the abatement from change in grazing management practices was due to changes in N_2O emissions. Clearly the difference in N_2O emissions between models and between modelled and observed requires work to resolve.

The quantity and type of data required to generate a modelled baseline, or scenario to be evaluated varied between the different models. One site (Armidale) collected much of the data required by SGS and GrassGro to enable a comparison between management practices to be made. Another (Lansdown) collected animal and estimated feed intake and digestibility data that enabled various comparisons to be made. The remainder used historical data. Our view was that the data required to enable the biosystems models to run was far beyond the capability of a farmer to collect on their property. We believe some simplified system that encourages collection of sufficient data to describe the farm just enough to encourage / support management change is preferred. We suggest that this be achieved through a 2 step process.

1. Conduct a sensitivity analysis of factors contributing to total emissions on a property and from that generate a simple, pragmatic set of measurements that can easily be obtained on farm. We envisage these being incorporated into

2. a simple recording system that enables calculation of total on-farm emissions, and highlights areas for practice change to reduce such emissions.

There are some concerns that if simple models are to substitute for real world measurements, that in an accounting system context, it would be prudent to generate data on methane and N_2O emissions from a wide range of livestock activities, to provide confidence in the models / calculators used to described the system, and to evaluate the effect of alternate management practices on emissions. We recommend that data on

1. methane emissions be collected from a range of livestock enterprises, along with data to support appropriate models, and

2. studies of the temporal relationships between N2O emissions and nutrient load from livestock, soil characteristics and rainfall events over a range of production systems be carried out, along with measurements required to model N_2O output..

This data could then be used to provide evidence that the outcomes of modelled scenarios have some relationship to the real world. This will engender some confidence that mitigation options do indeed result in reduced emissions of gases contributing to a greenhouse effect.

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1. Background

CFI methodologies for reducing CO_2-e from methane and nitrous oxide and for storing soil carbon require a standardised, simple to use and consistently accurate protocol upon which to base the accounting method.

In the RELRP program a number of demonstration sites were established to measure aspects of livestock production systems that should reasonably be expected to contribute data to a carbon balance sheet for each site. This was one component of the demonstration site process. Perhaps the primary purpose of the demonstration projects was to increase awareness of what was currently possible, to illustrate some of the requirements for data to underpin any CFI methodology that may subsequently arise, and to enable a comparison of methods to be undertaken across the different production systems demonstrated at each site.

Six (6) sites covering different geographical regions and production systems were chosen for the demonstration component of the project (Figure 1). Of these various processes for collecting on-ground data were used. Many used a historical process with data provided for each site by producers (or by the state agency responsible for the site / district in which the site was located).

Figure 1. Distribution of demonstration sites in the RELRP project.

The extent of data collection varied across the sites, as did the range of models used to estimate components of carbon balance (Table 1).

Table 1. Summary of enterprise, nature of data collected at each site and the method used to evaluate emissions and net carbon balance..

Site	Enterprise	Data Collection	Method of assessment	Contact and Project Reference
1. “Lansdown” near Townsville Qld	Beef Cattle	Fecal NIRS	Home Built calculator using equations from SCA (1990)	Dr Ed Charmley BCCH.1032/1037
2. Armidale NSW	Self replacing wool and meat sheep	Full soil, pasture and animal assessment with some CH_4 FTIR and N_2O measurements	GrassGro GrazFeed SGS Pasture Model FarmGas	Dr Malcolm McPhee BCCH.1033 BCCH.1039
3. Northern Midlands Tas	Self replacing sheep with trading enterprise	Farm inventory	FarmGas, Framework, SGS, GrassGro Stochastic	Dr Richard Rawnsley, Dr Karen Christie, Rowan Smith BCCH 1082
4. Terang District Vic	Dryland Dairy with 2 potential mitigation options	Scaled up data from Dairy 3030 demo project farms	DGas	Clare Leddin, Christie Ho and Graeme Ward BCCH 1081
5. Struan SA	Beef Grazing (different breeding and trading strategies)	Inventory plus some historical pasture and animal data	SGS Pasture model	Dr Nick Edwards BCCH 1038
6. Ridgefield, Pinjarra Hills WA	Sheep / wheat enterprise	Historical assessment	MIDAS	Dr Phil Vercoe, Dr Ross Kingwell BCCH 10XX

2. Project objectives

The aim of the synthesis project was to identify and discriminate the reasons why differences may result in yield and composition of emissions, and emissions intensities from enterprises examined using different deterministic models at the various national demonstration sites across Australia. This will be achieved by active discussion with individual researchers modeling existing RELRP sites. It is acknowledged that each stakeholder involved in, or affected by, the development of the CFI will have different information needs. There is however a need for work to be undertaken to determine applicability of analysis, the key points for discrimination between models, and the use of the modelling approach in the development of CFI methodologies. These outcomes are important to reduce the risk of 'conflict' during CFI method development where a range of model approaches may be taken to determine the impact of mitigation strategies. By using the RELRP demonstration sites as the benchmark farming systems (or components of farming systems) for the modelling exercise, a range of models can be examined under conditions where real-time measurements of methane emissions from livestock were undertaken. This approach provides a degree of realism to the evaluation processes.

The report to the Commonwealth will focus on analysis of different models and synthesis of model outcomes over a range of livestock production systems in different environments. It will aim to provide confidence in the ability of a range of different approaches to identify the likely magnitude of CO2e abatement from various potential CFI methodologies.

Objectives.
1. Examine, by active discussion with other research organisations, a range of option models for each demonstration site to (a) identify current net C balance and (b) to demonstrate a range of abatement options to reduce net carbon balance.
2. A report (in confidence) to the Commonwealth determining efficacy, boundaries of operation and confidence of modelling approaches used to develop CFI methodologies within the boundary of the RELRP demonstration sites

3. Methodology and Results

3.1 Site Summary

Complete details of each site data collected and results are provided in the reports.

They are briefly summarised in Table 1 above and a little more detail below. It is recommended that this report be read in conjunction with the full reports for each of these projects.

Site 1. **Lansdown near Townsville Nth Qld** (Charmley et al, 2012). Details of the site are provided in final report BCCH.1037. Data of pasture quality and estimated intake obtained using fecal NIRS were provided from a longitudinal study of cattle growth, over a one year period from November 2010 to November 2011. Animals were high grade Brahman, and measurements commenced post weaning. Initial live-weights were 255.5 ± 23.2 (sd) kg for 80 head and final liveweight 414.6 ±31.5 (sd) kg (n = 78).

Data

Cattle weights, feed intake and digestibility estimated using faecal NIRS over a 12 month period. There have been some measures of methane production in the field using the Open Path Laser technique.

Models and Methodology

Publication by Kennedy and Charmley (2012) of methane emissions from a wide range of tropical pastures indicates that emissions / kgDMI are in range 5 – 7.2% (mean 6.3%) of GE intake (or 12.2% of DE intake). This is lower than the Hunter group (Kurihara et al, 1999; McCrab et al, 2000) originally published for tropical grasses and lower after the corrections published by Hunter (2007). They are at the low end of the range published by Blaxter and Clapperton (1967) for temperate pasture species. The Lansdown group built a simulation model using SCA(1990) methodology, but reported that this provided estimates that did not compare well with pasture intakes estimated using fecal NIRS or the measured performance of cattle.

Site 2. **Armidale NSW** (McPhee, 2012). Data provided from a comparison of grazing systems (land classes) with different production potential. Sheep at different stocking rates, and going through full reproductive cycle and following fate of progeny.

Data

Extensive pasture quantity quality and growth measures. Extensive sheep weights, wool production, reproductive performance, lamb growth and carcass characteristics. Some field methane measurements using FTIR, some Nitrous Oxide measurements from soil. Soil measurements, including moisture at depth. Full recording of weather during trial. The data are presented in the final report for BCCH.1038, and outputs from simulations using this data as input were reported in the final report for project BCCH.1039.

Models and Methodology

Models used were

1) SGS Pasture Model (http://www.imj.com.au/consultancy/wfsat/wfsat.html).

2) GrassGro and Grazfeed (Freer et al, 1997; Moore et al 1997),

3) FarmGas (http://www.farminstitute.org.au/calculators/farm-gas-calculator).

Within these models, methane emissions and animal productivity were primarily driven by pasture inputs. Where measures of field methane were made using FTIR they had the potential to be compared using outputs from all three models (but that has not been done within the project). There are some global comparisons made between N_2O output from soils and modelled output, but a comparison of observed and simulated data over comparable time scales has not been conducted. Additional information was obtained from Dr McPhee to enable basic comparisons to be made between observed CH_4 emissions using FTIR and CH_4 emissions simulated by the SGS pasture model and GrassGro (Table 3).

Site 3. Mid North of Tasmania (Christie et al, 2011). Farm balance study of a typical high productivity lamb enterprise (which included both self replacing and trading enterprises on the same property).

Data

Numbers of stock / month with some weight data provided by farmer (on groups not individual animals)

Models and Methodology

FarmGas and the Sheep Greenhouse Accounting Framework calculator were used as the primary tools. Initial estimates of the CO2-e of key farm imports were generated using Simapro life cycle analysis software. Variation was assessed by adding a stochastic component over the outputs of the FarmGas calculator, and provided an assessment of the confidence (within the model framework) of the estimates.

Application. Options for abatement through change of management practice were explored. A number of different scenarios to the base calculation were considered including a)reduction of the age at first joining, b) dynamics of ewe replacement policy, c) change in ewe weights d) increase lamb weaning rates including from fewer ewes e) reduction in crude protein in the diet and f) reduction in lamb turnoff time. The Framework calculator was used for evaluation of most of these alternate strategies.

This project also provided an assessment of the strengths and weaknesses of the inventory based calculators (FarmGas and Framework) and the available biophysical models (GrassGro and SGS). They did not use either of the biophysical models because the complexity of the farming system used in this study was unable to be represented in these models. They recognised the comparative advantages of the biophysical models (SGS calculates N_2O, whereas GrassGro does not), but noted that SGS could not simulate a purchased lamb enterprise.

Site 4. Terang District Vic (Leddin et al, 2012). Dairy operation. Base farm modelled and 2 options for abatement assessed. Underpinning data was obtained from a long term dairy farm study in the region and scaled up to represent average dairy farms for the district.

Data

The “farm” studied was a scaled up version of a farmlet used as part of the DemoDairy project at Terang, SW Victoria. It was considered representative of farms in the region.

Models and Methodology

GHG emissions of the case study farm were estimated using DGas. Of the total farm emissions, methane and nitrous oxide were the most significant contributors to total CO_2-e emissions (contributing 56% and 18% of total CO_2-e emissions respectively). Abatement options considered were application of a nitrification inhibitor to pasture, and feeding oil supplements to dairy cows. Although these simulated strategies reduced CO_2-e emissions, the cost of implementing them would not be recovered either in increased productivity or through payments under the CFI at a carbon price of $25/tonne.

Site 5. Struan SA (Edwards 2012). Self replacing beef breeder and beef trader / finishing operation using a range of management options including the Technograze system at Struan research farm.

Data

Historical performance from trials conducted under similar conditions at Struan, was used to set up and calibrate the SG pasture model.

Models and Methodology

The SGS Pasture model was used for this project. A number of different scenarios were compared. The baseline scenarios were self-replacing breeder operations and trader/ finisher operations in SE South Australia. Various mitigation options were investigated, including a change from continuous to rotational grazing – which resulted in small (1.8%CO_2-e) reduction in emissions, due largely to slightly lower N_2O emissions, where stocking rate wasn’t changed, or by 12.2% CO_2-e where stocking rate and management were optimised. The later effect was due in part to a 36% reduction in N_2O emissions. The opportunity was taken to simulate emissions of animals differing in potential efficiency (essentially differences in potential fat deposition) in a trader / finisher enterprise. Not surprisingly these simulations suggest that by both increasing growth and improving efficiency of feed utilisation it is possible to reduce methane emissions. The data used for improved efficiency were from lines differing in fatness (which is one of the phenotypic consequences of selection fro efficiency).

It was not possible to simulate the effects of management strategies in the Technograze system using SGS due to the structure of model inputs required. I suspect that Dairy Mod does not have this limitation and could have been used if it were available.

Site 6. Ridgefield. Pinjarra Hills WA (Kingwell, 2012). Simulated sheep / wheat property using district average as baseline.

Data

Mainly district average data adapted to the 1305 hectare sheep wheat property west Pingelly. Data base inside MIDAS used as core data.

Models and Methodology

MIDAS was used to simulate a number of options to reduce methane emissions. These primarily addressed change in enterprise mix. The report indicated that by changing the relative amount of land under cropping cf sheep grazing that reduction in methane emissions were possible, although these were insufficient to offset costs at proposed carbon price of $25/tonne. They noted a carbon price of >$60/tonne would be required to make sequestration activities break even. It is not clear that the MIDAS model by itself was able to account for negative impacts of cropping on soil carbon or of increased N_2O emissions associated with increased use of nitrogen fertilisers. These sources and sinks of GHG were not accounted for in the report.

None of the sites were able to estimate net carbon balance with the techniques used.

3.2 Comparison of modelled with measured methane emissions

3.2.1 Site summaries

Models of animal performance and subsequent emissions of CH_4 and carbon balance are useful, but they need to be tested against measurements wherever possible. There were 2 studies conducted in this series in which it was possible to compare measured with calculated methane emissions (although the measurements of methane were rudimentary and / or not necessarily contemporaneous).

At **Lansdown** in North Queensland, a single study of methane emissions on a subset of the demonstration animals was made over the period September to October 2011. It was necessary to coral approx 40 animals around water (to concentrate the methane to enable measurements with a Laser technique). The animals were corralled from approximately 0900 to 1600 h for a number of days to enable measurements of methane emissions to be taken. Although there were some behavioural changes imposed on the animals they were largely post absorptive and would be expected to be digesting, and eructing the consequences of, the morning grazing session during the period of measurement. Serial estimates of dry matter intake (DMI) and dry matter (DMD) and organic matter digestibility were obtained from all (80) animals in the group over a year (reported in BCCH.1037). Methane emissions were derived from the mean intake (DMI), DMD, and from the weight and average daily gain (ADG) for the period around the measurement of methane emissions using the laser methodology.

The results are summarised in Table 2. They show that estimates of methane emissions derived from a number of methods of calculation were within the observed range. It was noted that the prototype model used in BCCH.1037 underestimated intake and therefore emissions compared to those measured using the Laser method. However, it is well known that the basis for estimating intake in *Bos indicus* cattle grazing tropical grasses in the SCA (1990) system underestimates measured intake. An example of the potential error in using the SCA calculation system with inappropriate intake functions can be seen in BCCH.1037 where the reported liveweight gain was 159kg over the year of the study and the simulated gain was 13 – 30 kg (the higher value was with simulation of the inclusion of legume in the available pasture). Clearly the simulated data did not match production outputs, and without seeing the outputs, it is highly likely that it grossly underestimated feed intake. It should be possible for the Lansdown team to verify this, by comparison of estimated intake using NIRS with modelled estimates using their prototype model.

Table 2. Comparison of methane output g CH_4/ hd / d estimated using a Laser technique on a subset of cattle used in the Lansdown study and various estimates derived from fecal NIRS data and modelled using cattle weight and weight gain. Data were collected in September and October 2011 as part of a study to describe the intake and weight gain of growing Bos indicus (Brahman) cattle over an annual cycle.

The cattle were 430 ± 31 (sd) kg, ADG was 0.4kg/d. Intake estimated using fecal NIRS was 7.5 ±0.9 (sd) kg / d and Dry Matter Digestibility 51 ± 1.2 %.

	CH_4 g/animal/day
Measured CH_4 (Laser)	136-238
Estimated CH_4 using:-	
Prototype SCA based calculator (a)	40-160
Fecal NIRS (b)	
Kennedy and Charmley (2012) 6.3% GEI	149.5 (cv 12%)*
Kennedy and Charmley (2012) 12.2% DEI	151.5 (cv 12%)
Blaxter and Clapperton (1965)	161 (cv 12%)
DMI based on Weight and ADG (c)	176
BeefGreenhouse V9N (d)	
Temperate pasture	174
Tropical pasture	228

a) from final report BCCH1037

b) calculated from fecal NIRS data appended to final report BCCH1037

c) Estimated using intake calculated from rudimentary energy balance calculations and estimated digestibility

d) Estimated from BeefGreenhouse V9N Eckhart (2008) modified Jan 2011

* cv = coefficient of variation of intake estimated using fecal NIRS (cv of DMD was <2%) n= 74-80

Of further note, is the observation that Beef Greenhouse V9N indicates methane output on tropical pasture to be at the higher end of the observed range and substantially higher than estimates derived from temperate pasture and calculated from intake using fecal NIRS data to inform a range of reasonable assumptions about methane production per unit feed energy consumed. At the time that Beef Greenhouse V9N was built, the published data indicated that methane yield / GE ingested in tropical cattle (based on corrections to earlier data published by Hunter, 2007) was substantially higher than subsequently published by Kennedy and Charmley (2012).

At **Armidale** in Northern NSW, methane emissions of a subgroup of sheep and lambs (described above and in BCCH1039) in the field were measured using FTIR equipment over several weeks in 2011. It was possible to compare the measurements using FTIR with those simulated using a number of different simulation models. Table 3 below shows the comparison between FTIR measurements and the outputs derived from the SGS pasture model, GrassGro and FarmGas. Estimates of methane emissions using three rudimentary estimates using actual animal weight and weight gain are also shown.

Table 3. Comparison of actual v's simulated performance and methane output was possible for only one period at the UNE Trevenna site (Armidale NSW). The simulations below were carried out using the SGS pasture model, GrassGro and FarmGas as described in Final Report BCCH 1039. and a generic method using liveweight and liveweight change to estimate energy requirements and therefore feed intake where the method of calculation of methane emissions ranged from that used in the SGS pasture model to that described by Blaxter and Clapperton (1965) as used in GrassGro. The measurement of methane output by FTIR was within the simulation period.

Flock 1 (Low Productivity)	**Ewe Wt (kg)**	**Lamb Wt (kg)**	**gCH_4 / h/ d**
Observed values	N = 16	n= 15.5	
8/3/11	46.9 ± 4.7	35.9 ± 4.9	
4/4/11	46.5 ± 4.7	37.0 ± 4.0	17.5[a]
Simulated values			
SGS 21/3/11	48.4	35.6	15.5
GrassGro	45.6	35.9	20.1
FarmGas			17.5[b]
Rudimentary DMI Calculations from energy requirements to match observed production [c]			SGS 6% GEI 15.3 Blaxter (1960) 8% GEI 20.4 B & C (1965)

			19.9
Flock 5 (High Productivity)			
Observed values	N = 32	n= 31	
8/3/11	48.1 ± 4.5	38.4 ± 3.1	
4/4/11	47.6 ± 10	40.5 ± 3.1	19.5[a]
Simulated values			
SGS 21/3/11	49.4	40.9	14.7
GrassGro	45.6	38.8	19.1
FarmGas			18.3[b]
Rudimentary DMI Calculations from energy requirements to match observed production [c]			SGS 6% GEI 17.9 Blaxter (1960) 8% GEI 24.0 B & C (1965) 22.3

a) = values reported are mean / head measured over several days using FTIR

b) = sum of enteric plus other wastes (~99.98% enteric)

c) = Calculated using DMI derived from energy requirements to support observed weight and weight gain (feed DMD 67%). The first value is derived from methane as 6% of GEI as used within the SGS pasture model, the second used methane energy loss as 8% GEI (Blaxter (1960) and the third is derived from the equations published by Blaxter and Clapperton (B&C, 1965).

3.2.2 Summary of comparison of observed CH_4 emissions with modelled estimates at RELRP demonstration sites.

With the exception of the prototype SCA based calculator used on Lansdown data, all other calculated (or simulated) estimates of methane emissions were within the likely range of error of measurement. There does appear to be a systematic difference between simulation packages. In the North (Lansdown), the BeefGreenhouse V9N (Eckhart, 2008) provides estimates using temperate pasture and Tropical pasture. The differences between both pasture types are because of use of earlier (higher) estimates of methane yield from tropical pasture (e.g. Hunter, 2007). These have subsequently been revised down according to the data presented in Kennedy and Charmley (2012), which indicates that methane yield (%GEI) in tropical pastures is similar to reported values for temperate pastures. Table 2, demonstrates that the temperate pastures option of Eckhart (2008) provides similar estimates as calculations from estimated intake using fecal NIRS and from weight and weight gain using the equations of either Blaxter and Clapperton (1965) or derived from the factors in Kennedy and Charmley (2012).

At Armidale, all modelled estimates were slightly higher than measured methane emissions, but within measurement error. Modelled estimates are reported for the month in which the FTIR measurements were made. Simulations using GrassGro provided higher estimates than the SGS pasture model. The primary difference in methane emissions between packages is due to the estimation of a) feed intake (both quality and quantity) due in part to variation in estimates of pasture availability and quality between the models and b) the calculation protocol for estimating methane emissions from ingested feed. For example, the SGS pasture model uses a flat proportion of gross energy ingested converted to methane energy (6% for pasture diets, 4% for concentrates) whereas GrassGro uses the full Blaxter and Clapperton (1965) function – which uses digestibility and level of feeding to derive the proportion of feed energy lost as methane energy. To understand the effect of assumptions about the amount of methane as a proportion of ingested energy a separate estimate using intake derived from weight and weight gain and estimated digestibility is shown. The values for methane gCH_4C/ h/ d derived from that calculation show that much of the estimated differences between the SGS pasture model and GrassGro are due to the method used to generate CH_4 from ingested feed, rather than estimated differences in ingested feed.

This view is reinforced by the results obtained with an uncalibrated SCA based model which underestimated feed intake and therefore methane emissions at Lansdown. Despite this, it was possible to have some confidence in the Lansdown data because of the independent estimates of feed intake and quality obtained on the cattle using NIRS.

There was no independent method used to estimate intake in the Armidale study. Comparison of modelled estimates with measured methane emissions using FTIR was possible for a relatively short period. It is of note, that estimates of methane emissions based only on estimates of intake derived from data on liveweight and weight gain and digestibility of feed covering the period of measurement of methane output with FTIR were not substantially different. This suggests that the modelled estimates were close to reality in the Armidale study.

There are a limited number of reported studies in which methane emissions were measured and feed intake estimated in grazing animals. Jones et al (2011) reported data on measurements of methane emissions by Angus cows from low and high residual feed intake selection lines (summarised in Table 4, below) using open path FTIR.

Table 4. Estimate of methane output measured using FTIR v's that estimated from intake and digestibility using the equations from Blaxter & Clapperton (1965) and using 6% GEI as per SGS. Data from Jones et al (2011).

Line/ State	Cow Weight (kg)	Pasture DMD	Est. DMI (kg)	FTIR gCH_4/d	gCH_4/d by B&C (1965)	gCH_4/d SGS
HRFI / Pregnant	510	55	10.9	133	243	206
LRFI	481	55	9.81	125	218	185
HRFI / Lactating	535	81	15.0	246	334	283
LRFI	494	81	12.9	168	287	243

The data from Jones et al (2011) show that although the relationships between groups were the same measured using FTIR and estimated by different modelling techniques, the values obtained with FTIR are considerably lower than predicted from models, or from rudimentary calculations of methane from independent estimates of feed intake. It is vaguely possible that this difference is real in that it is known that pregnant and lactating sheep have higher rumen outflow rates than dry (non-pregnant / non- lactating) sheep, and that the production of methane is reduced at high rumen outflow rates. There is insufficient data to rule out this possibility, although it is more likely that the measured FTIR values for methane emissions reported are underestimates.

In summary, accurate estimates of feed intake and proportion of ingested energy lost as methane are required to match simulated with observed values. However, within reason, as long as the behaviour of the models is close to real life, the absolute numbers don't matter when implementing different strategies to mitigate emissions,. i.e. the important element is that the relative effects of a mitigation strategy are model independent. A systematic bias can be tolerated as long as the behaviour of the model is correct. However, without reliable field data it will be difficult to determine the bias between estimates obtained with different models and actual data. This can be addressed by further studies in which data on mobs or flocks of livestock are measured using open path techniques (FTIR or Laser) and sufficient data to support modelling during the same measurement period (or at least over a period in which the field measures are taken) is collected.

In an accounting methodology context it is important that an estimate of the amount of methane mitigation provided by a particular technique is not overestimated by the calculation method chosen. However, if one, conservative, modelling technique is chosen, the risk of overestimation of mitigation is reduced. An alternative is to use a method of proportionality (e.g. mitigation by suggested method / total enteric emissions) to scale the effect of the mitigation strategy. This will be discussed further below.

Summary – comparison of measured methane emissions in the field and modelled estimates.

The modelled / calculated estimates of methane emissions (with the exception of the model based only on SCA intake equations for *Bos indicus* cattle) provide values for methane emissions are similar to those measured in the field. The key component in the modelled estimates is an accurate estimate of feed intake, although using liveweight and weight gain as proxies and inferring intake from energy balance provides similar estimates as where feed intake has been estimated using NIRS. However, there are limited field measures of methane emissions from groups of animals to compare modelled vs measured methane emissions.

3.3 Comparison of modelling methods across sites

One of the anticipated outcomes of the demonstration sites was that by using similar modelling methodologies across sites it would be possible to determine the robustness of the predictions for a range of different models / calculators. Unfortunately, it was not possible to achieve this.

Only 2 sites collected new data (Lansdown and Armidale) and 2 others (Terang and Struan) used existing data. The Tasmanian site used farm specific data and the Western Australian site used average regional data. As shown in Table 1, there was no common calculation method used across all sites (although it was hoped that each would use FarmGas).

There were a number of reasons given for choice of models. The primary reason was “it could be used with our data structure”. For instance, sites that used rotational grazing were unable to easily use the SGS Pasture Model and GrassGro. Nonetheless, a work-around method was established for the Armidale site. For the Tasmanian work a choice was made to model a complex farm system with multiple enterprises and fodder crops with management permutations beyond the capability of the biophysical models used. Also it seemed that the complex biophysical models required a broad but detailed knowledge across soils, pastures and animals (skills not universally available across the 6 sites) in order that the user successfully characterise start up parameters for the simulations. This also required data on parameters that were not recorded in some of the historical data sets used. a heavy reliance on data ,

However, for Lansdown and Armidale, the data suggest that for methane emissions, it is possible to derive realistic estimates of methane emissions using a number of different methods, some of which require only minimal data on pasture.

Incorporation of pre-farm emissions. Only two reports (TIAR and DPIVic) quantified the pre-farm contribution to emissions as CO_2-e. An independent LCA was conducted on the Armidale site (but not reported). These indicate that the contribution of pre-farm sources of (embodied) emissions was small relative to the on-farm emissions. The TIAR report provided the most detail about pre-farm emissions. It indicated that there were calculator specific differences (FarmGas estimated pre-farm emissions to be higher than the Framework calculator), the proportion of pre-farm emissions was 10% or less of the total (pre and on-farm emissions) for the 2 enterprises calculated. For the dairy enterprise simulated by DPIVic 18% of total emissions were pre-farm. On-farm emissions were dominated by enteric emissions (methane). N_2O generally contributed less than 1/3 of the amount of the on-farm CO_2-e. CO_2 production from fuels and electricity used on-farm was generally less than 5% of total farm emissions.

The greenhouse specific calculators (FarmGas, DGas, Framework) were able to provide estimates of emissions from pre-farm sources (embodied energy costs in fertilisers, transport fuel use, electricity etc) in addition to on-farm sources (methane, N_2O and CO_2 from fuel use). Those reports where farm / enterprise level models GrassGro, SGS Pasture and MIDAS were used did not provide estimates of energy expenditure on-farm for operational purposes or embodied costs off-farm nor does GrassGro estimate N_2O. In the case of the Armidale site which used FarmGas, SGS Pasture and GrassGro and conducted an independent LCA, the pre-farm emissions were (note, this was not reported).

There were marked differences in estimates of on-farm emissions derived by different models. This was best illustrated in the TIAR report (summarised in Figure 2 below). FarmGas provided markedly lower estimates of methane and nitrous oxide emissions than the Framework calculator. The most striking difference is in nitrous oxide emissions from animal waste where the FrameWork calculator estimate is from 4.7 to 8.2 times the estimate from FarmGas.   The difference in methane emissions calculated by the FrameWork calculator is from 1.3 to 1.7 greater than that estimated by FarmGas. It is also worth noting that the embodied emissions in the purchased lambs (i.e. those generated before purchase) are not included in the comparison of enterprises.

There was substantially less variation between estimates of methane emissions with SGS Pasture and GrassGro models, and the FarmGas calculator with Armidale data (see Table 3). It could be concluded that each of these tools provided similar estimates for methane emissions. However, it was not possible to compare estimates of nitrous oxide emissions. SGS Pasture estimates of N_2O emissions contributed from 18-28% of the on-farm emissions of CO_2-e, and approximately 10 x higher than observed values (although the measured values were taken on a parallel pasture to that simulated and did not have animal waste input at the level estimated by the SGS Pasture model). GrassGro does not report N_2O emissions. The proportional contribution of N_2O to total farm emissions calculated using FarmGas were approximately 13% (McPhee et al 2012). From the preliminary LCA (Brock, pers comm.) N_2O contributed 22% (2kgCO_2 –e /kg LWt) on the flats vs 18.5 (1.39 kg CO_2 -e/kg LWt)on the hills.

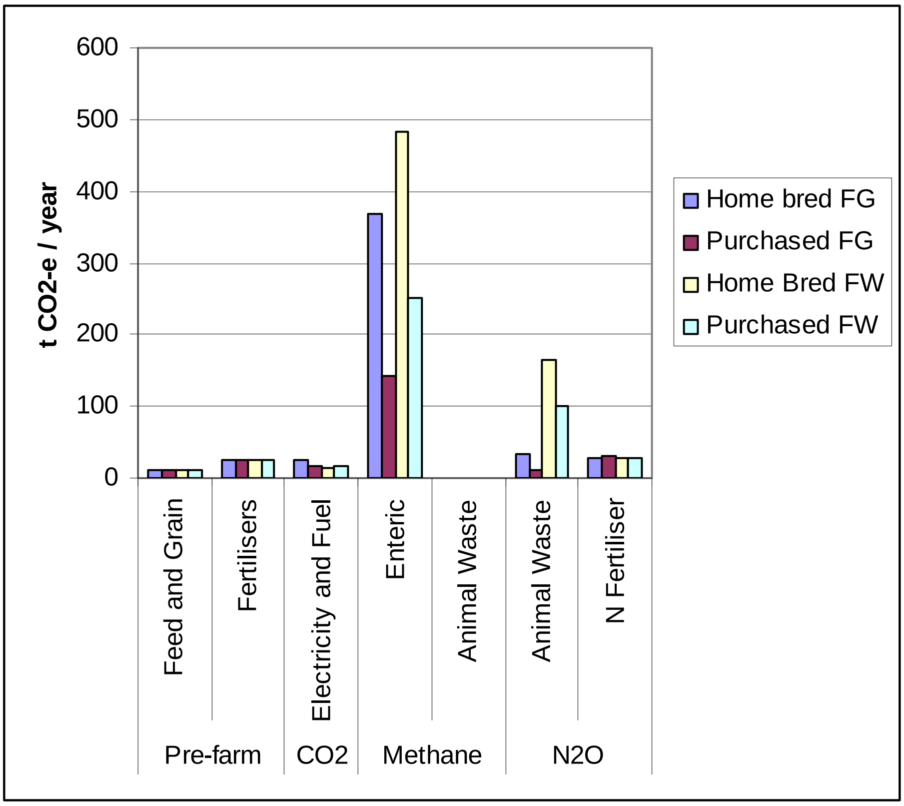

Figure 2. Comparison of FarmGas (FG) and Framework (FW) calculator estimates of the 2 base sheep enterprises (home bred and purchased lambs) in Mid North of Tasmania (Christie et al, 2011). Note the systematic difference between FG and FW in estimates of enteric methane and nitrous oxide emissions. As noted above, pre-farm emissions in the purchased lambs option were not calculated.

Nitrous Oxide. The contribution of N_2O to total farm emissions is high using the SGS model. This is of some concern, because as noted by Edwards (2012) a significant part of the difference in emissions from the management practices simulated in his report were due to differences in estimated N_2O emissions. The SGS model was used for that study, and it provides estimates of N_2O emissions higher than FarmGas and higher than observed. This suggests it would be prudent to include more direct measures of N_2O emissions in future studies to enable comparison between simulated and observed values to be made. Such studies will need to be more comprehensive that the rudimentary measurements made at the Armidale site. Nitrous oxide emissions from soil are influenced by nitrogen load, soil type (including pH), soil water content and soil temperature. These are modelled within the SGS model, along with drivers of variability including rainfall events, and seasonal variation in temperature. However, comparisons between modelled estimates and measured N_2O emissions under conditions approaching the normal temporal variation observed in grazing systems were not made in the present demonstration projects. Given the high variation between estimates of N_2O emissions derived by different models, and the reported instances where differences in management strategies were attributed to N_2O emissions, it would be prudent to include measurement of N_2O emissions in pertinent demonstration sites in the future. By pertinent, we mean those sites and times where it would be expected that N_2O emissions would be substantial and variable.

Assumptions underlying different models. Because of the different assumptions used within each model / calculator estimated intake of feed differs between different calculation method. Conversion of feed ingested into methane also differs between the different models. So that values obtained by different methods using the same pasture inputs will not be identical. This is illustrated in Tables 2-4 in the case of methane. In the case of N_2O, only the SGS Pasture model provided estimates of N_2O output, although the values derived from the model were more than an order of magnitude higher than those measured (Armidale site). Although it is recognised that N_2O emissions are highly variable, this observation suggests that further work to compare modelled with measured estimates of N_2O are required in pasture systems. This is especially important when it is considered that a substantial part of the predicted difference in emissions from rotation compared with continuous grazed systems in the SE of South Australia is reported to be due to differences in N_2O emissions (numbers derived using the SGS pasture model). It is worth noting that GrassGro does not report N_2O emissions. We are unaware if any of the other calculators have been subject to a direct comparison between estimated and measured N_2O emissions.

The factors / algorithms used in the NGGI differ to those used in the simulation models. However, an additional source of variation is the validity of the state wide seasonal defaults for liveweight, Diet DMD%, Diet CP%, reproduction and Standard reference weight. In other work (DJ Alcock, pers comm.) we have compared LCA's using enteric methane direct from GrassGro (combined with N_2O and manure CH_4 estimated from FarmGas and prefarm/fuel use estimates in Simapro) with LCA's using Farm gas driven by pasture inputs derived from GrassGro and LCA's which simply use the NGGI default parameters for the region in question. Setting the direct GrassGro outputs as the bench mark the second option described only generates about 85% of the enteric methane while relying on the NGGI defaults produces only about 75% of the direct Grassgro outputs. These observations support the suggestion that sensitivity analysis on factors affecting emissions of CH_4 and N_2O needs to be conducted..

3.4 Implications for CFI methodology

None of the sites used the same data collection procedures. The models used were different across sites. It was suggested that FarmGas and/or the appropriate Framework calculator would be applied across all sites, but this was not done. There is insufficient data in the reports to independently compare the same models across sites do.

Two sites (Armidale and Lansdown) collected data to allow a comparison of models to measured CH_4. Although the modelled data from Lansdown was outside the range of data observed with the laser technique, values calculated using estimates of DM intake and digestibility from fecal NIRS were within the range of measured values. At Armidale, the modelled estimates bracketed the measured values. These suggest that a number of different calculation techniques show qualitatively similar behaviour across different production systems. Under such circumstances those which require the least and simplest measurements are likely to be superior in practice.

In practice, the gathering of data used to derive values used by the SGS and GrassGro models is beyond a normal farmer. The new version of FarmGas also seems to be somewhat more complicated and demanding of inputs than the previous version.

It would be useful to take each of the models and calculators and establish a lowest common level at which the methods used for estimation of methane (and to a lesser extent N_2O) are based and run a series of sensitivity analyses on them. From such an analysis it would be possible to develop a simplified procedure for use in practice, but understand the trade-offs made by each step in the simplification. In many ways this would also inform the research debate about the components of the system that are potentially the most important to change in any abatement strategy.

The models used in this work range in complexity and flexibility. There application in the development of CFI methodologies varies accordingly. For he most part they create capacity to test the likely impact of a change in technology or management intended to reduce emissions. The more complex farm system models provide the greatest capacity in this regard. Not only do they provide estimates of the change in emissions (not withstanding the questions over there capacity to model N20) but they put this in context of the likely response in whole farm outputs and profitability and some idea of the risk of “leakage” and measures to control this. These issues are critical to the likelihood of adoption (Alcock and Hegarty 2011). Once a mitigation option has been screened in such a way and the action/s clearly defined then the accounting procedures must be much simpler than any of the models evaluated provide. In the simplest case it may require only some evidence of the mitigation action having been carried out (eg the addition of oil to the diet of a dairy cow) while for others it might be necessary to make some assessment of the level of mitigation by using simple animal measures to calculate the change in emissions. This approach might take the form of simple calculators using the minimum of inputs and deriving the mitigation impacts in a manner similar to a partial budget (Makeham and Malcom 1981). The calculator tools would need to account for not only changes in direct emissions from a specific origin (eg enteric methane) but any changes in pre-farm emissions due to the inputs used and any concomitant changes in other emssions such as N20 that results from the change.

Issues arising

If the demonstration sites reflect current best current practice in terms of obtaining and using data required to estimate emissions reduction in grazing enterprises, there are a few points to note. Where sufficient data on animal performance and feed intake and digestibility was collected, the recommended calculation procedures using NGGI calculations (based around the Blaxter and Clapperton, 1965, or approximations reported previously Blaxter 1960, or used in SGS Pasture Model) were close enough. However, on most of the demonstration sites, such data wasn’t available, which required the models / calculators to use historical / district data as inputs. In practical terms these models / calculators require more detailed information than likely to be available for most farms. It depends upon the purpose that such models / calculators are deployed. It may be possible to use the detailed models to explore consequences of different abatement practices and to use simpler (in terms of data requirement) calculators for practical use.

If it is planned to implement a CFI methodology using some of these accounting processes (models / measurement systems) they need considerable work to simplify (= make them more robust). The first step requires a sensitivity analysis to determine the critical parameters that contribute to on-farm emissions. First principles suggest that total feed intake (number of stock x feed intake x time present) is the single biggest driver of enteric emissions.

There is a sustainable economic optimum rate of utilisation of pasture. If an astute producer were to reduce one of the three factors in the equation above, it is likely that he will act to increase one or both of the other two in order to achieve the sustainable economic optimum pasture utilisation. If he were to do this, emissions intensity may decrease, but it is possible that absolute emissions do not decline. Since absolute emissions reduction is what the CFI issues credits for, the decision of individual farmers to buy into a methodology relies on the marginal loss from reduced utilisation being exceeded by the marginal gain from the value of CFI credits. Estimates from work conducted elsewhere (DJ Alcock pers comm.) indicate that the value of a tonne of CO_2-e will need to be much more than $23/tonne to make most of the current options viable even without accounting for the costs of transition from one management/technology to another.

4. Discussion and Conclusions.

The six demonstration sites separately and together have provided valuable lessons about the limits to modelling emissions from a range of different production systems and in some cases provided examples of possible abatement opportunities.

Where it was possible to compare modelled / calculated emissions with measured values (2 sites for methane, 1 for N_2O) the data suggest that in general the methane component of accepted models works within error of measurements taking into account the underlying assumptions. With regard to N_2O there was simply insufficient data to have any confidence in the measurements. The fit between models and measurements reflect the different nature of emissions. In the case of methane, to a first approximation the agreement between measured and predicted methane emissions is a consequence of feed intake and digestibility, which are essentially continuous processes in a ruminant production system (and although predictable on a time scale of weeks, subject to large day to day variations). With respect to N_2O, it is recognised that emissions are a function of variation in among other things, soil moisture, and subject to considerable short and long term variation in train with variation in weather conditions. Accordingly estimation of these emissions are intrinsically more variable. Nonetheless, the variation seen between different modelling / calculation approaches suggests that there are systematic differences in the calculators used to derive estimates. This requires further examination to resolve. Such examination would be well served if it were coupled to more intense measurement in the field to provide a means of comparison of modelled vs measured values.

Ruminant production systems are the consequences of interactions between the species and physiological state of animals present and the dynamics of feed supply.

The production of methane is primarily a function of ingested feed which can be computed from animal production data. This requires far less data than the current systems that require an estimate of available feed and feed quality. Tables 2-4 show that it is possible to obtain realistic estimates of methane emissions from simple measures of animal performance (numbers, weight, weight gain and, not shown, reproductive status).

A simplified accounting system requires an understanding of the sensitivity of methane emissions to factors which can reasonably be accounted for by producers, and the construction of a calculator that accounts for these inputs taking account of the sensitivity of predictions to simple on-farm factors. The benefits of a simplified approach to accounting for actions in proportion to their effects on reducing emissions would make the link between actions on farm and change in emissions more obvious and therefore more likely to be considered and implemented taking account of the prevailing Carbon price. Nonetheless, it is imperative that more on-farm measurements of methane emissions by groups of livestock, and N_2O by soils under grazed pastures, be made to provide evidence that the modelled / calculated estimates of emissions are credible. Such data will make it easier to meet the requirements for a CFI methodology to be supported by peer reviewed science.

5. Recommendations.

The work in this report provides an overview of the more detailed work conducted at each of the demonstration sites / modelling examples. It highlights the following complementary needs.

Data Collection to provide more comprehensive evaluation of existing models.

Methane. Additional measurements of methane emissions over a range of field conditions closer to the normal variation in real production systems are required. Measurements of methane emissions in the field should be taken in conjunction with sufficient measurements, including measurements of feed intake, to enable calculated / modelled estimates of methane to ne made.

Nitrous Oxide. Data on nitrous oxide emissions over time and of the nutrient load from grazing animals and soil characteristics should be collected at several different sites. This would provide the opportunity to compare the different methods of accounting for nitrous oxide emissions in the models / calculators with real data. It would assist evaluation of the factors used to calculate the proportion of nitrogen excreted from animals in different calculators.

This data, together with simultaneous measurements of inputs required by models or calculators would provide the confidence that modelled estimates are close enough to reality to provide a realistic basis for accounting for baseline and mitigation options upon which future CFI methodologies can be verified.

To facilitate use of models in both development of CFI methodologies and to provide data that could inform the accountability of CFI methodologies we suggest:-

Simplification of models / calculators

Sensitivity Analysis. To facilitate development of calculators that can be used on farm to underpin CFI methodologies we suggest that an analysis of the factors underpinning the contribution of methane and nitrous oxide emissions be undertaken, This would assist the development of simpler calculators / accounting systems by putting focus on the major factors contributing to greenhouse gas emissions on farm, thereby enabling development of management actions to reduce emissions.

Develop calculation procedures that require less on-farm data. Less intensive data requirements would facilitate on –farm uptake of results from either the demonstration sites or the models used to evaluate them. At present the models and calculators have quite extensive data requirements. Some of this is provided as default values in the current methods (e.g. default settings in FarmGas and the Framework calculator, and example farms in GrassGro), However for an accounting framework, and to enable producers to evaluate alternatives they can implement, it would be helpful if the data requirements could be reduced to the minimum possible to achieve the desired outcome. In this report we have provided an example of using weight and weight gain for estimating methane production.

The sensitivity analysis should provide insights to rationally reduce the data needs to evaluate actions designed to alter at least methane emissions from grazing animals.

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