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Abstract

This study examined the total greenhouse gas (GHG) emissions (tonnes of carbon dioxide equivalents; t CO_2e) and GHG emissions intensity of lamb production (kg CO_2e/kg dressed weight) of a prime lamb enterprise, located in the Northern Midlands of Tasmania. Using the FarmGas and Framework calculators the GHG emissions intensity of lamb production was estimated at 9.0 and 14.7 kg CO_2e/kg dressed weight, respectively. Several management and genetic improvement abatement strategies were assessed. This included reducing the age of joining maiden ewe lambs to 7 months, increasing weaning rates either with or without changes to ewe numbers, improving ewe efficiency or extending ewe longevity. It was estimated that the adoption of these strategies alone could reduce the GHG emissions intensity of lamb production by between 3 and 12%.

A stochastic modelling technique was adopted to account for the variation that exists in key emission factors when undertaking a deterministic assessment of GHG emissions. This provided an assessment of the confidence level around the mean result and furthermore, highlighted the emission factors which must be described more accurately to improve emissions estimations. A review of currently available tools to determine their usefulness in estimating farm GHG emissions and changes in emissions resulting from changes in management practices is also provided.

Executive summary

The Australian red meat industry is committed to finding ways to reduce on-farm greenhouse gas (GHG) emissions through research and development. To achieve this there is need for a whole of farm perspective on the GHG emissions contribution, based on best practice data acquisition and analysis. An analysis of lamb GHG emissions reported that the average Australian sheep farm produced 584 t CO_2e/annum (RIRDC 2009). However, it is well established that there is significant variation in farm emissions due to varying production levels and significant variation in GHG emissions intensity (kg CO_2-e/unit of product) due to management and farming system influences. As there is a paucity of information relating to the whole of farm emissions associated with lamb production in Tasmania, the objectives of this study were to:

- quantify the GHG emissions (including embedded emissions in key inputs) from a lamb producing enterprise in Tasmania,
- evaluate the usefulness of various science based modelling tools to estimate farm GHG emissions and their suitability for monitoring and reporting of abatement strategies, and
- evaluate the interaction of various GHG emissions sources within a lamb enterprise.

This study examined the GHG emissions associated with the lamb production component of a mixed lamb/cropping enterprise located in the Northern Midlands of Tasmania. The lamb production component was segregated into two sub-enterprises; a home-bred lamb enterprise producing 1,572 lambs (34,630 kg dressed weight) and a purchased lamb enterprise producing 5,470 lambs (accumulating 37,614 kg dressed weight on-farm). Greenhouse gas emissions included pre-farm embedded emissions from key farm inputs (i.e. grain, fodder and fertilisers) in addition to GHG emissions from the consumption of electricity and diesel fuel. Total farm GHG emissions, as estimated using the FarmGas (Australian Farm Institute 2009) and the Sheep Greenhouse Gas Accounting Framework (Eckard 2008) calculators, were 652.8 and 1,061.0 t CO_2e/annum, respectively. This equated to a GHG emissions intensity of lamb production of 9.0 and 14.7 kg CO_2e/kg dressed weight, respectively. The primary difference in result between the two calculators was due to FarmGas predicting substantially lower daily intakes based on state-derived values rather than realistic daily intakes based on farm-specific data in the Framework calculator.

Several management and genetic improvement abatement strategies available for the home-bred lamb enterprise were evaluated using the Framework calculator. These included reducing the age of joining maiden ewe lambs to 7 months, increasing weaning rates, improving ewe efficiency or extending ewe longevity. These strategies showed that the GHG emissions intensity of lamb production could be reduced by between 3 and 12% for the home-bred lamb enterprise. Only two abatement strategies were explored for the purchased lamb enterprises; an increase in daily live weight gain and a reduction in the crude protein % in the diet, resulting in an emissions intensity reduction of 6 and 10%, respectively.

A review of four currently available tools for estimating GHG emissions of lamb production was undertaken. Two inventory calculators (FarmGas and Framework) and two biophysical models (GrassGro (Moore *et al.* 1997) and SGS pasture model (Johnson *et al.* 2003)) were assessed for their strengths and weaknesses in firstly, estimating the GHG emissions for a lamb enterprise and secondly, the ability to model changes to management practices and their influence on GHG emissions. FarmGas and the Framework calculators derive their GHG emission estimations from IPCC and Australian methodologies, algorithms and emission factors. In contrast, GrassGro and the SGS pasture model, in most instances, do not conform to this inventory approach. However, these biophysical models do have some comparative advantages, such as influences of soil type and climatic conditions on pasture and livestock production. By exporting the relevant information from these biophysical models into inventory calculators, applies the strengths of both to achieve a more accurate assessment of the whole of farm emissions.

Whilst the empirical calculators can provide an estimation of GHG emissions based on scientifically accepted emission factors, it is important to consider sources of uncertainty with these calculations. A Monte Carlo stochastic uncertainty assessment using the Framework calculator highlighted the influence of uncertainty around key emission factors on the GHG emissions intensity of lamb production. This study showed that there was a 90% likelihood that the GHG emissions of lamb production fell between 19.4 and 28.4 kg CO_2e/kg dressed weight for the home-bred lamb enterprise. This is in contrast to the static (i.e. non-stochastic) assessment which found the GHG emissions of lamb production to be 18.2 kg CO_2e/kg dressed weight. Similarly, the stochastic uncertainty assessment estimated that there was a 90% likelihood that the GHG emissions of lamb production for the purchased lamb enterprise fell between 10.9 and 17.0 kg CO_2e/kg dressed weight, with the static assessment estimating an emission intensity of lamb production for this enterprise to be 11.5 kg CO_2e/kg dressed weight. The static assessment of GHG emissions intensity of lamb production in the current study was found to have a low probability (<15%) of occurring, highlighting that the uncertainty associated with nearly all emissions factors was associated with a high level of emissions. For example, the minimum, static (most likely) and maximum emission factor for N_2O emissions from urine was 0.003, 0.004 and 0.03, respectively.

Before any potential assessment of abatement can be undertaken it is paramount that an accurate assessment of the farm baseline emissions is undertaken. To achieve this, accurate collation of farm data is critical. Only when an accurate representation of the farm data and a baseline assessment of GHG emission are complete can abatement strategies be explored. However, as shown in this study with the Monte Carlo uncertainty assessment, the baseline estimation of GHG emissions can vary quite considerably, much greater than any currently available abatement strategy, due to the uncertainty that exist with a number of emission factors. To minimise the uncertainty associated with the varying emissions factors, a greater level of research is required to firstly, better quantify the GHG emission factors under varying environmental and management conditions and secondly, understand when conditions are most conducive to higher emission. This needs to be reflected when estimating GHG emissions so that the uncertainty around GHG emissions estimations can be minimised.

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Background

The State of Tasmania is a small contributor to Australia's greenhouse gas (GHG) emissions (Figure 1). Based on 2009 figures, Tasmania was responsible for approximately 8.4 metric tonnes of carbon dioxide equivalents (Mt CO_2e) compared to 564.5 Mt CO2e nationally (DCCEE 2011). While this constitutes only 1.5% of the national emissions, Tasmania has an obligation to reduce its GHG emissions. To achieve this, the Tasmanian Government has set an ambitious target of reducing the state's emissions to at least 60% below 1990 levels by 2050 (Gerardi *et al.* 2009). To achieve this target, significant emissions reduction across all sectors will be required.

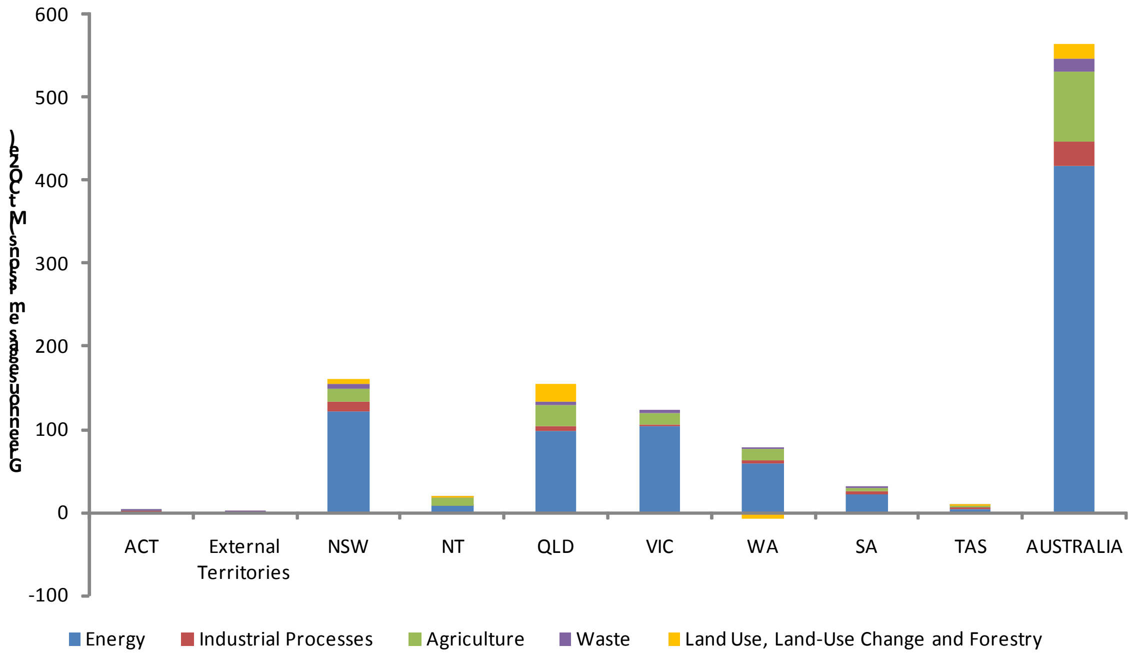

Figure 1. National and State greenhouse gas emissions (metric tonnes of carbon dioxide equivalents) from energy, industrial processes, agriculture, waste and land use, land use change and forestry (Source DCCEE 2011)

Within Tasmania, agriculture is the 2nd largest source of GHG emissions, behind stationary energy, producing 1.9 Mt CO_2e/annum; equivalent to 23% of the State's GHG emissions (DCCEE 2011). Agriculture plays a very important role in Tasmania, with a farm gate value of $1.1 billion (ABARE 2010). While the farm gate value of dairy, vegetables and beef were valued higher (National Farmers' Federation 2011), sheep meat production still remains a very important enterprise for Tasmania and in 2009 was valued at approximately $45.6 million (National Farmers' Federation 2011). Based on 2010 values, Tasmania had 2.0 million head of sheep representing approximately 2.9% of Australia's flock (Australian Bureau of Statistics 2011). There are many aspects of Tasmania that are desirable for sheep meat production, such as the temperate climate enabling a long growing season, meat having low chemical residuals and a ban against using hormone growth promotants (Thompson *et al.* 2009). However, the implications of Australia having to reduce its GHG emissions as part of policies like the Kyoto Protocol, will also impact on the Tasmania sheep industry.

While there have been studies undertaken for various sheep enterprises (e.g. merino wool, dual purpose merino, prime lamb) in other states of Australia (e.g. Howden *et al.*, 1996; Kopke *et al*. 2008; Biswas *et al.* 2010; Peters *et al.* 2010; Alcock and Hegarty 2011; Browne *et al.* 2011), there appears to be few examples of assessments relating to either partial or whole-of-farm GHG emissions associated with lamb production in Tasmania (Hall 2010). This study estimates the whole-of-farm GHG emissions associated with lamb meat production using two currently available GHG emissions calculators. This study also explores potential abatement strategies and estimates their influence on reducing the GHG emissions intensity of lamb production in Tasmania.

Plate 1. Home-bred lamb and ewe flock grazing perennial ryegrass

Project objectives

The objectives of this specific project are:

1. To quantify the GHG emissions (including embedded emissions in key inputs) from a lamb producing enterprise in Tasmania;
2. Evaluate the usefulness of science based modelling, including existing tools such as FarmGAS, Framework calculator, GrassGro and SGS to estimate farm GHG emissions and changes in emissions resulting from changes in management practices;
3. To provide an assessment on the applicability of the suite of available science based modelling tools for possible monitoring and reporting of abatement strategies;
4. To provide knowledge on the GHG emissions associated with lamb production in Tasmania and the interactions of components within the farm system on these emissions.

Methodology

1. Lamb enterprise

a) Description of the lamb enterprise

A mixed prime lamb/cropping enterprise, located in the Northern Midlands of Tasmania (41.8°S, 147.0°E) was identified, with an initial farmer interview undertaken in August 2011. The property is 481ha (effective) of which ~ 40% is used for annual cropping with the remainder under perennial pasture (perennial ryegrass/clover and lucerne; see Appendix 1 for farm map). Cash crops (peas, potatoes, poppies and beans) are grown during the spring period. After harvesting, these same areas are sown with annual forages (winter wheat, annual ryegrass and forage rape) to supply autumn and winter feed to the lamb enterprise. Paddocks are cropped for three years before being sown back to perennial ryegrass pasture as part of a cropping/ annual forage/pasture rotation.

The property produces approximately 6,000 lambs for slaughter each year, with approximately 1,500 coming from the farms' breeding stock (Poll Dorset cross Coopworth). The remaining lambs are purchased as trade lambs (1st and 2nd cross) at approximately 38kg live weight for fattening. The lamb enterprise was separated into two production systems; a home-bred lamb enterprise, with a study period from July 2010 to June 2011, and a purchased lamb enterprise, with a study period from December 2010 to November 2011. Separating the two enterprises allowed us to better capture the timeframe, and therefore GHG emissions, for each enterprise.

For the home-bred lamb enterprise, the mature ewes commenced lambing in August while the maiden ewes commenced lambing in September. The weaning rate was 1.36 for the mature ewes and 1.0 for maiden ewes, resulting in 1,917 lambs being weaned. Approximately 345 lambs were retained for replacements (ewes and rams) with the remaining 1,572 lambs sold for slaughter at approximately 50 kg live weight (22 kg dressed weight). For the purchased lamb enterprise, 5,470 trade lambs were purchased in mobs between December 2010 and September 2011. These lambs were sold when they reached an average live weight of between 49 and 60 kg (mean of 54 kg live weight; 24.5 kg dressed weight).

Forage supply to the lambs of both enterprises consisted of 88 ha of irrigated perennial forages (i.e. 66 ha perennial ryegrass/clover and 22 ha lucerne) and 202 ha of irrigated annual crops (i.e. 181 ha of winter wheat or annual ryegrass and 21 ha of forage rape). The forage rape crop was grazed by lambs between December 2010 and March 2011. Lucerne was grazed by lambs from December 2010 to June 2011. The irrigated annual ryegrass and winter wheat was grazed by lambs from mid March to September 2011. When there was insufficient feed from these three sources, lambs grazed on the irrigated perennial ryegrass/clover pastures. In addition, lambs were also fed a minimal amount of supplementary feeding (i.e. grain, hay and silage) in autumn and winter. Feed quality analysis (dry matter digestibility (DMD %) and crude protein (CP %)) of the irrigated pastures and supplements was undertaken throughout the study period. Two ryegrass pasture samples were analysed, with DMD values of 79 and 85% and CP values of 25 and 28%. Two silage samples were analysed as 72 and 78% DMD and 18 and 22% CP. A hay sample was also analysed as 69% DMD and 10% CP. While there was no analysis for grain, lucerne or the forage rape, these feeds are generally reported as being high in DMD, with lucerne and forage rape also generally reported as being high in CP (Heard and Wales 2009). Therefore, for the lamb enterprises, we assumed a diet of 75% DMD and 24% CP year round. These assumed values are lower than the analysed samples but given that these samples were taken when quality was likely to be high, there may have been periods when feed quality was lower.

The ewes and rams grazed on 191 ha of dryland perennial ryegrass/clover with minimal supplementary feeding in autumn and winter. The ewes and rams grazed dryland pastures so seasonal conditions dictated feed quality. We assumed relatively high feed quality figures in winter and spring (i.e. 75% DMD and 20-22% CP) and lower feed quality in summer and autumn (i.e. 60 & 70% DMD, respectively, and 14% CP both seasons).

b) Systems boundary and timeline

As this is a mixed prime lamb/ cash crop enterprise, only the GHG emissions associated with lamb production was considered in this assessment; emissions associated with the growing and harvesting of the cash crops were not included. The lamb enterprise was separated into two sub-enterprises; the home-bred lamb enterprise and the purchased lamb enterprise (Figures 2 and 3). The system boundary included the emissions generated with the production and/or manufacturing of key farm imports (e.g. fertiliser, grain, hay and silage), the emissions generated with the refining/extraction and consumption of diesel fuel and the consumption of electricity. However, it did not include the GHG emissions associated with the raising of the purchased lambs prior to entering this farm. In addition, this assessment did not include the GHG emissions associated with the transportation of key farm inputs to the farm gate, transportation of purchased lambs onto the farm, transportation of all lambs off farm or the GHG emissions associated with slaughtering and meat processing.

For the home bred lamb, the timeline began in July 2010 and concluded in June 2011 (Figure 2). The home-bred lamb enterprise was segregated into the four seasons of winter (July 2010 to September 2010), spring (October 2010 to December 2010), summer (January 2011 to March 2011) and autumn (May 2011 to June 2011).

The purchased lamb enterprise commended with the first mob of purchased lambs in December 2010, with the last purchased lambs sold in November 2011 (Figure 3). The purchased lamb enterprise aligned with typical seasonal definitions with summer being December to February, autumn (March to May), winter (June to August) and spring (September to November).

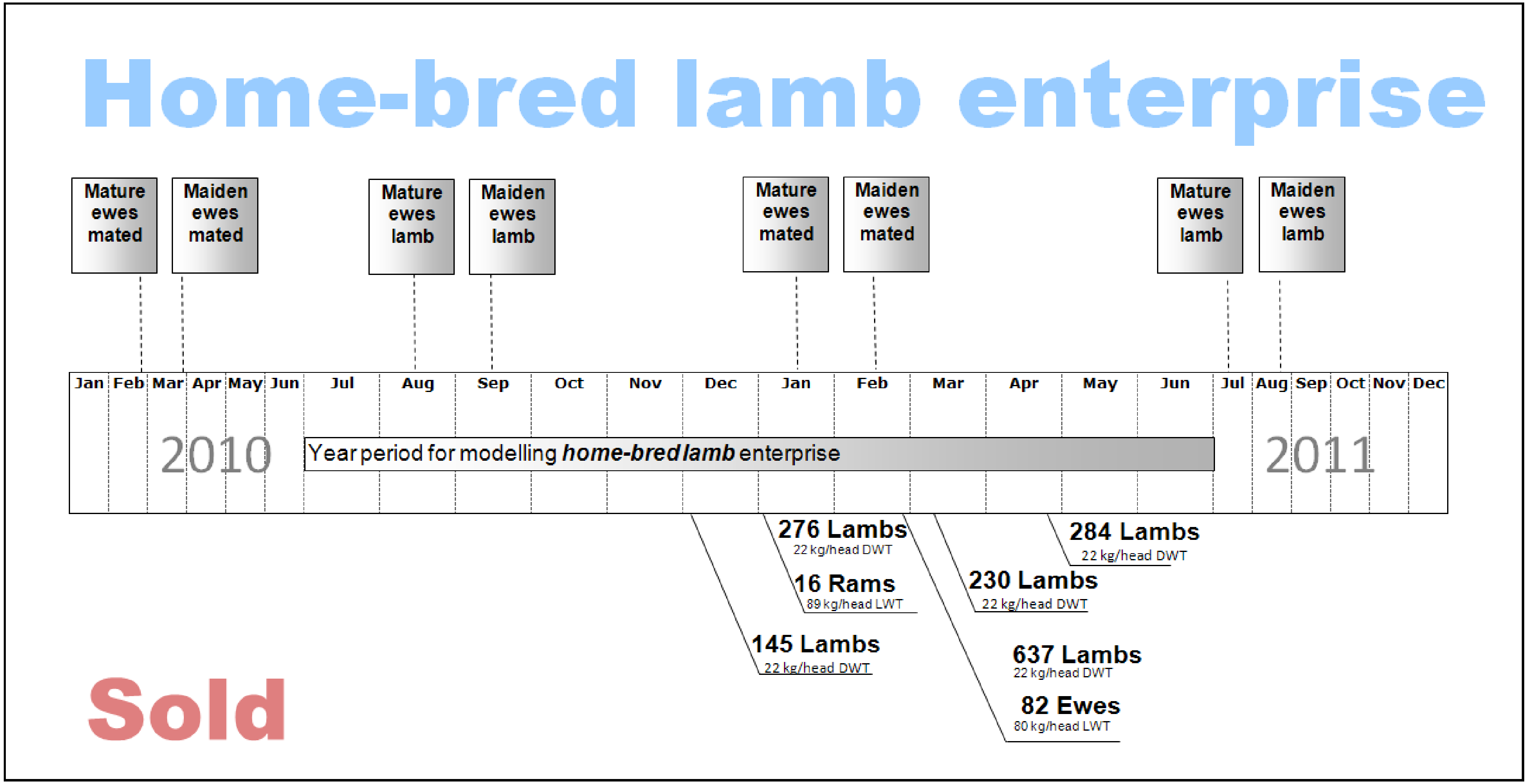

Figure 2. Timeline for the home-bred enterprise showing the joining and lambing time for the mature and maiden ewes and the number and weight of lambs, ewes and rams sold each month (DWT = dressed weight (kg/head), LWT = live weight (kg/head))

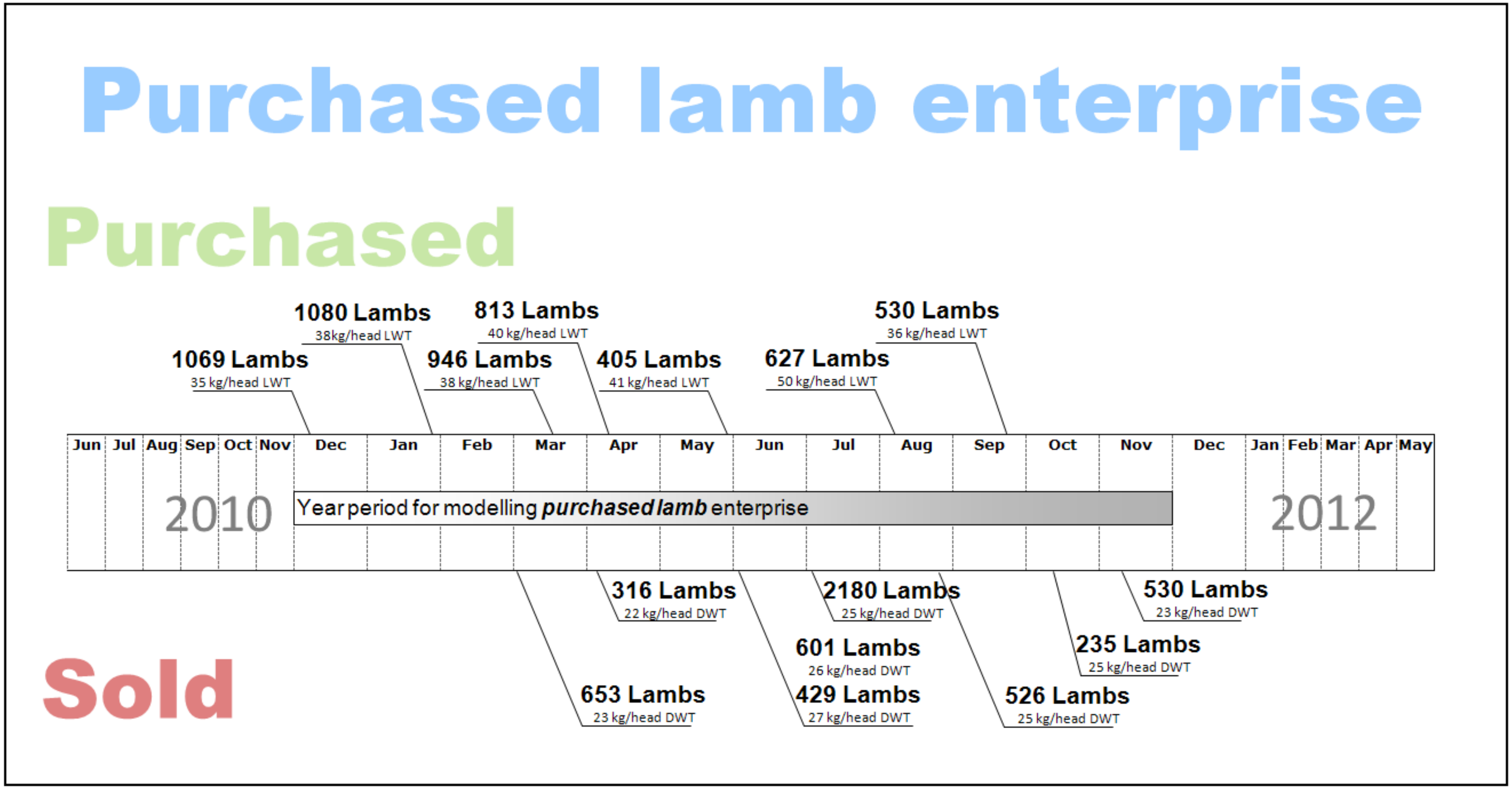

Figure 3. Timeline for the purchased lamb enterprise showing the number and weight of lambs purchased and sold each month (DWT = dressed weight (kg/head), LWT = live weight (kg/head))

2. Modelling GHG emissions

2.1. Models selected

Two empirical calculators were selected to estimate the GHG emissions of lamb production. These were the FarmGAS calculator (herein referred to as FarmGAS; Australian Farm Institute 2009) and the Sheep Greenhouse Accounting Framework calculator (herein referred to as the Framework calculator; Eckard 2008). In addition, the GrassGro model (herein referred to as GrassGro; Moore *et al*. 1997) and the SGS pasture model (herein referred to as SGS; Johnson *et al.* 2003) were also explored to model the biophysical aspects of the farm system using historical climatic data.

The FarmGas and Framework calculators were developed from the Intergovernmental Panel on Climate Change methodology (IPCC 1997), as currently used in the Australian National Inventory (DCCEE 2009). These calculators were able to estimate the GHG emissions associated with methane (CH_4) and nitrous oxide (N_2O) emitted on-farm in addition to carbon dioxide (CO_2) from electricity and fuel.

GrassGro and SGS are mechanistic biophysical models that do not conform to IPCC methodology for estimating GHG emissions. GrassGro estimates enteric CH_4 emissions, based on the same equation developed by Blaxter and Clapperton (1965) that is also incorporated in the FarmGas and Framework calculators. However, it does not completely conform to the current national inventory methodology (DCCEE 2009) as it does not estimate CH_4 from animal waste, N_2O emissions from N fertiliser applications or N_2O emissions from dung and urine deposition. The SGS model estimates enteric CH_4 emissions based on intake with each kg DM of forage and concentrate equivalent to 19.89 and 13.26 g CH_4, respectively. These emission factors do not conform to the national inventory methodology (DCCEE 2009). Unlike GrassGro, the SGS model does estimate N_2O emissions from N fertiliser and animal dung and urine deposition, but the methodology does not conform to national inventory methodologies (DCCEE 2009). While the two biophysical models do not conform to the nation inventory methodology, the strength of these two biophysical models lies in their ability to model the impact of climatic and seasonal variability on pasture supply and how this influences farm management practices such as stocking rate or requirements for supplementary feeding. In addition, the SGS pasture model can examine the dynamic nature of soil N_2O emissions based on varying soil parameters, climatic conditions and stock numbers.

2.2. Key farm inputs

Simapro life cycle assessment software (Simapro 2006) was used to determine the CO_2e emissions associated with the production of key farm imports. The amount of nitrogen (N), phosphorus (P) and potassium (K) applied (Table 1) was converted into equivalent amounts of urea (46% N), triple superphosphate (18% P) and potassium chloride (50% K) and multiplied by their corresponding emission factor of 0.89, 0.83 and 0.13 kg CO_2e/kg product, respectively. An emission factor of 0.02 kg CO_2e/kg product was used for lime applications. The amount of purchased grains, hay and silage was multiplied by their corresponding emission factor; 0.25 kg CO_2e/kg DM for hay and silage, and 0.30 kg CO_2e/kg DM for grain.

Table 1. Key farm inputs and their corresponding greenhouse gas emissions

	Input	Amount	GHG emission (t CO_2e)
Fertiliser inputs	Nitrogen (t/annum)	13.2	25.6
	Phosphorus (t/annum	4.8	22.2
	Potassium (t/annum)	0.7	0.2
	Lime (t/annum)	100.0	2.0
Purchased feeds	Grain (t DM)	12.6	3.8
	Hay (t DM)	18.5	4.6
	Silage (t DM)	50.0	12.5
Energy consumption	Electricity (kWh)	21,400	6.0*
	Diesel (L)	7,500	25.2

* GHG emission for only 20% of electricity consumed as ~ 80% of Tasmania's electricity is from clean sources, with only 20% supplied via burning of coal from Victoria (Hydro Tasmania)

2.3. On-farm carbon dioxide from energy

Diesel refining/manufacturing and consumption emits 0.61 (Simapro 2006) and 2.75 kg CO_2e/ litre, respectively (DCCEE 2009). In 2010/11 approximately 7,500 L of diesel was used for the lamb enterprise, predominantly in the planting of annual crops and pastures. This equated to an emission of 25.2 t CO2e/annum (Table 1). Approximately 80% of Tasmania's electricity is generated through renewable sources, with around two-thirds of Tasmania's electricity from hydro-generation and smaller amounts through gas and wind. The balance of Tasmania's electricity is supplied via BassLink through the burning of predominantly brown coal from Victoria (Hydro Tasmania 2009). The lamb enterprise consumed approximately 21,400 kWh of electricity in 2010/11. Electricity has an emission factor of 1.4 kg CO_2e/ kWh resulting in 6.0 t CO_2e/annum being attributed to electricity consumption (Table 1).

2.4. Estimating farm GHG emissions

The GHG emissions from embedded pre-farm, energy consumption and N_2O emissions from N fertilisers could not be segregated between the two enterprises. Therefore pre-farm emissions, CO_2 emissions from energy consumption and N_2O emissions from N fertiliser were allocated across both enterprises using the ratio of total dressed weight sold from the home-bred lamb enterprise to total dressed weight sold from the purchased trade lamb enterprise.

The two lamb enterprises were modelled separately in the Framework calculator to ascertain the animal-based emissions (i.e. CH_4 from enteric fermentation, CH_4 and N_2O from animal dung and urine). However, the functionality of the FarmGAS calculator would not permit the purchased lamb enterprise to be modelled in isolation. To overcome this, the two lamb enterprises were assessed together within the FarmGAS calculator (Appendix 2). The home-bred lamb enterprise (Appendix 3) was then assessed separately and the difference in GHG emissions between the two analyses was used to determine the GHG emissions of the purchased lamb enterprise.

Two co-products were produced from the home-bred lamb enterprise (meat and wool) while all GHG emissions from the purchased lamb enterprise was allocated to meat production. A ratio of 87:13 for meat and wool for the animal-based emissions was applied for the home-bred lamb enterprise (Browne *et al.* 2011). Appendix 1 and 2 presents the farm input data for FarmGas and the Framework calculators, respectively.

3. Modelling potential abatement strategies

There have been several studies describing strategies to reduce GHG emissions associated with sheep enterprises (e.g. Cruickshank *et al.* (2009); Eckard *et al.* (2010); Hegarty and McEwan (2010); Hegarty *et al.* (2010); Alcock and Hegarty (2011); Cottle *et al.* (2011)). Generally abatement strategies are broken down into several broad areas such as animal management practices or diet management practices for lowing enteric CH_4 production or soil management practices for lowering N_2O emissions.

A review of potential abatement strategies by Cruickshank *et al.* (2009) provided the basis for abatement strategy assessment. The various abatement strategies assessed focused on management and/or genetic improvements. All abatement strategies were reviewed using the Framework calculator (with the exception of abatement strategy 7 (changes to daily live weight gain)). We did not explore any abatement strategy in FarmGas due to the inability to alter some aspects of FarmGas to reflect changes to management and/or genetic improvements associated with several of the abatement strategies. Seven abatement strategies were assessed for the home-bred lamb enterprise. In addition, reducing the concentration of CP in the diet and increasing daily live weight gain was repeated for the purchased lamb enterprise.

1. Ewe age at first mating- This farm already joins maiden ewe lambs at 7 months of age as opposed to joining at 19 months of age. As this is an abatement strategy that is frequently examined, we explored the benefit that this enterprise currently achieves in reducing its total GHG emissions by reducing the joining age of maiden ewes to 7 months. We assumed there were no changes to any other management practices, such as requiring additional feed (most likely achieved through grazing additional land) and resources to maintain an additional unproductive mob of un-joined maiden ewes.

2. Ewe longevity- In 2010/2011 this enterprise lambed 285 maiden ewes; equivalent to a replacement rate of 19% per annum and ewes culled on average every 5.2 years. We explored the effect of extending the mean ewe longevity to 6 years on GHG emissions. Total ewe numbers were maintained the same as the baseline at 1,485 with this strategy now consisting of 1,238 mature ewes and 247 maiden ewes. The weaning rate of lambs from mature and maiden ewes was also maintained the same as for the baseline, at 1.36 and 1.0 lambs/ewe, respectively. This strategy resulted in a slight increase in the number of lambs weaned, 1,931 compared to 1,917, due to increases to the number of mature ewes with higher weaning rates compared to maiden ewes with lower weaning rates. With fewer maiden ewes required, the proportion of replacement ewe and ram lambs was retained as the same as for the

baseline lamb enterprise. Overall a total of 1,632 lambs were sold with this strategy compared to 1,572 for the baseline system. We assumed no changes to management practices or resource requirements as a result of the additional lambs. While replacement rate was 19%, only 82 mature ewes were culled during 2010/2011, so to maintain a similar cull rate to the baseline, this strategy culled 84 mature ewes half way through the study period.

3. Ewe efficiency- Reduce mature and maiden ewe live weights by 10% to 63 kg with no influence on lamb productivity.

4. Increase lamb weaning rates by 10%- The baseline lamb enterprise weaning rate was 1.36 for mature ewes and 1.0 for maiden ewes. We explored the benefit of increasing weaning rates by an absolute value of 10% to 1.46 for mature ewes and 1.1 for maiden ewes to achieve an overall weaning rate of 1.39. This resulted in an additional 148 lambs being weaned resulting in an additional 3,240 kg dressed weight. This strategy assumed lambs reached their target slaughter weight at the same rate as for the baseline enterprise. To achieve this, additional feed would be required. We assumed that the additional lambs would occupy land currently being used by the purchased lamb enterprise, with that impact not considered in this assessment. We also assumed that additional resources such fuel, electricity, grain, forages and fertiliser were not required and that the higher lamb weaning rates did not result in an increase in ewe culling rates.

5. Increase weaning rates by 10% from fewer ewes- This strategy explored the benefits of reducing ewe numbers in combination with a higher weaning rate to achieve the same number of lamb sales as per the baseline lamb enterprise. Weaning rates were increased by an absolute value of 10% as per strategy 4 above. The ratio of maiden to mature ewes was maintained at 19%, resulting in mature ewe numbers being reduced by 86 to 1,114 while maiden ewe numbers were reduced by 20 to 265. The baseline enterprise culled 82 mature ewes so to maintain the same culling rate of 6.8%, 76 mature ewes were culled half way through the study period.

6. Reduce dietary crude protein concentration- The crude protein concentration of the baseline diet was estimated to be 240 g/kg DM for both lamb enterprises for all seasons based on feed analyses. This was reduced to 140g/kg DM based on information in the 'Making More From Sheep' manual (AWI and MLA 2008a). All other aspects of the enterprise remained the same as per the baseline farm system. For example, we assumed that there was no change to the diet's DMD and therefore no change to the enteric CH_4 emissions, as a result of feeding a diet with a lower concentration of CP.

7. Changing the rate of live weight gain- The baseline home-bred lamb enterprise took on average 195 days to reach a target live weight for slaughter; equivalent to a mean daily growth rate of 0.24 kg/day. The baseline purchased lamb enterprise took on average 90 days to reach the target live weight for slaughter; equivalent to a mean daily growth rate of 0.19 kg/day. This strategy could not be directly explored in the Framework calculator as the estimation of daily enteric CH_4 emissions is not

dependant on daily live weight gain. However, by knowing the animal's daily energy requirements to achieve the desired daily live weight gain and by knowing the digestibility of the feed and its corresponding metabolisable energy value, required daily feed intake values could be derived. This could then be used to estimate daily enteric CH_4 emissions. Using this approach, changes in daily live weight gain through associated changes in diet quality and daily intakes was explored such that the time lambs spend on the farm could be reduced by 20 and 10 days for the home-bred and purchased lamb enterprises, respectively.

4. Strengths and weaknesses of the various calculators and models

The two inventory calculators (FarmGas and Framework) and two biophysical models (GrassGro and SGS) were compared and contrast to each other with respect to estimating GHG emissions. In some instances, the calculators or the models have a similar strength/ limitation and these are listed. In addition, an assessment of the ability of each calculator and model for assessing the possibility for monitoring and reporting of abatement strategies was determined as part of this assessment.

5. Stochastic uncertainty assessments

Stochastic uncertainty assessments was carried out using @Risk version 5.7 (Palisade 2009), an add-in package to Microsoft Excel, which allows uncertain variables to be defined as probability distributions. The effect of uncertainty around certain emission factors in estimating GHG emissions were assigned probability distributions based on triangular distributions where the minimum, maximum and most likely values were included (Hardaker *et al.* 1997). The most likely emission factors for N_2O emissions (Table 2) were according to Australian NGGI methodologies (DCCEE 2009) and for some emission factors these were lower than the IPCC (2006) most likely emission factors. For example the IPCC (2006) defines the emission factor for direct N_2O emissions from N fertiliser as 0.01 compared to the Australian NGGI methodology (DCCEE 20090) of 0.004 and 0.003 for pastures and crops, respectively. As the Australian NGGI methodology (DCCEE 2009) does not determine minimum and maximum emission factor values (Table 2), these were defined by the IPCC (2006). The Monte Carlo simulation method involves randomly selecting values for variable risk inputs (in this instance emission factors), from the specified probability distributions, and whole farm outcomes (in this instance total GHG emissions) are estimated. A large number of iterations were compiled to form a distribution of possible outcomes for total GHG emissions and the corresponding emissions intensity of lamb production. The results reported in this analysis are based on 10,000 iterations. This was undertaken for both lamb enterprises within the Framework calculator. Given the web-based format of the FarmGas calculator, the analysis was not possible to be repeated for this calculator.

To enable the stochastic uncertainty assessment to be undertaken for enteric CH_4 emissions, the method of estimating enteric CH_4 emissions were altered in the Framework calculator. The IPCC (2006) methodology estimates sheep enteric CH_4 emissions as 6.5% ± 1% of gross energy intake (GEI) for mature sheep and 4.5% ± 1% of GEI for sheep < 1 yr of age (Table 2). This is in contrast to the Australian NGGI (DCCEE 2009) where enteric CH_4 emissions are based on factors such as feed quality, feed availability and daily intakes.

Daily intakes were converted into daily GEI by multiplying daily intakes (as calculated in the Framework calculator) by 18.45 (i.e. MJ energy content of 1 kg DM; IPCC 2006). These daily GEI values were then multiplied by either 6.5% for mature sheep or 4.5% for immature sheep, divided by 55.65 (i.e. MJ content of one kg CH_4; IPCC 2006) and then multiplied by 21 to convert enteric CH_4 loss to CO_2e emissions.

Table 2. Minimum, most likely and maximum emission factors for the stochastic uncertainty assessment

GHG and source	Minimum*	Most likely†	Maximum*
Enteric CH_4 emissions- sheep > 1 yr age *	0.055	0.065	0.075
Enteric CH_4 emissions- sheep < 1 yr age *	0.035	0.045	0.055
Direct N_2O emissions from N fertilisers- pastures	0.003	0.004	0.03
Direct N_2O emissions from N fertilisers- crops	0.003	0.003	0.03
Direct N_2O emissions from animal waste- urine	0.003	0.004	0.03
Direct N_2O emissions from animal waste- dung	0.003	0.005	0.03
Indirect N_2O emissions from volatilisation of N fertiliser and animal waste	0.002	0.01	0.05
Indirect N_2O emissions from leaching/runoff of N fertiliser and animal waste	0.0005	0.0125	0.025
Indirect FracGas for N fertilisers	0.03	0.1	0.3
Indirect FracGas for animal waste	0.05	0.2	0.5

* IPCC (2006)

† DCCEE (2009) with the exception of enteric CH_4 emissions (IPCC 2006)

Plate 2. Home-bred lamb and ewe flock grazing perennial ryegrass

Results

1. Lamb GHG emissions

The home-bred lamb enterprise produced 1,572 lambs for slaughter with an average dressed weight of 22.0 kg; equating to a total farm production of 34,630 kg dressed weight. For the purchased lamb enterprise, only the weight gain that occurred within the farming system boundary was considered. The 5,470 purchased lambs entered the farm system with a total of 213,958 kg live weight; equivalent to an average live weight of 39.1 kg/lamb. The farmer was only able to supply dressed weights at point of sale. Therefore to calculate the amount of live weight gained within the farming system boundary, the sale dressed weights were converted into live weight using an average dressed weight at slaughter of 45% live weight (supplied by the farmer with similar figures reported by AWI and MLA (2008b)). The total live weight sold for the purchased lamb enterprise equated to 297,544 kg resulting in a live weight gain within the farming system boundary of 83,586 kg (37,614 kg dressed weight). The total dressed weight produced from the two enterprises was 72,244 kg on a 48:52 ratio of home-bred lamb to purchased lamb.

Total pre-farm embedded and CO_2 from energy consumption were estimated to be 70.7 and 31.2 t CO_2e/annum, respectively. Nitrous oxide emissions from N fertiliser emissions were estimated to be 56.4 or 55.8 t CO_2e/annum when using the FarmGas and Framework calculators, respectively (Table 3). Using the ratio of 48:52 to allocate emissions to the home-bred and purchased lamb enterprises, this resulted in the home-bred lamb enterprise emitting 33.9 t CO_2e/annum from pre-farm embedded emissions, 15.0 t CO_2e/annum from CO_2 (energy) emissions and either 27.0 or 26.8 t CO_2e/annum from N_2O emissions from N fertilisers when using FarmGas or the Framework calculator, respectively (Table 3). The purchased lamb enterprise was estimated to emit 36.8 t CO_2e/annum from pre-farm embedded emissions, 16.2 t CO_2e/annum from CO_2 (energy) emissions and either 29.4 or 29.0 t CO_2e/annum from N_2O emissions from N fertilisers when using FarmGas or the Framework calculator, respectively (Table 3).

The total home-bred lamb enterprise GHG emission, as estimated by FarmGAS and the Framework calculator, was 415.8 and 629.3 t CO_2e/annum, respectively (Table 3). Enteric CH_4 emissions was the largest single source of GHG emissions; accounting for 77 and 67% of total enterprise GHG emissions when estimated using the FarmGas and the Framework calculators, respectively. Given that the home-bred lamb enterprise sold 34,630 kg dressed weight, this equated to an estimated GHG emissions intensity of lamb production for this enterprise of 12.0 and 18.2 kg CO_2e/kg meat when estimated using the FarmGAS and Framework calculators, respectively (Table 3).

The total purchased lamb enterprise GHG emissions, as estimated by FarmGAS and the Framework calculator, was 236.9 and 431.7 t CO_2e/annum, respectively (Table 3). Enteric CH_4 emissions was the largest single source of GHG emissions; accounting for 60 and 58% of total enterprise GHG emissions when estimated using the FarmGas and Framework calculators, respectively. Given that the purchased lamb enterprise sold 37,614kg dressed weight, this equated to a GHG emissions intensity of lamb production of 6.3 and 11.5 kg

CO_2e/kg meat when estimated using the FarmGAS and Framework calculators, respectively (Table 3).

A total of 72,244 kg dressed weight was produced within the farming system between the two enterprises. The GHG emissions intensity of total lamb production for the farming system was estimated to be 9.0 and 14.7 CO_2e/kg meat using the FarmGAS and Framework calculators, respectively (Table 3). Enteric CH_4 emissions was the single largest source of emissions and contributed 71 and 63% of total farm GHG emissions when estimated using the FarmGas and Framework calculator, respectively. Nitrous oxide emissions from animal waste was estimated as 23% of total farm GHG emissions with the Framework calculator but only estimated as 6% of total farm GHG emissions when estimated using FarmGas. Nitrous oxide emissions from N fertilisers contributed 8 and 5% to total farm emissions for the FarmGas and the Framework calculators' results, respectively. Although the GHG emissions from pre-farm and CO_2e from energy were the same for both calculators, given that the calculators estimated different total farm GHG emissions, the proportion of emissions from each two sources was different for each calculator. With FarmGas, pre-farm and CO_2 from energy contributed 10 and 4% of the total farm GHG emission, respectively. With the Framework calculator, pre-farm and CO_2 from energy contributed 6 and 3% of the total farm GHG emission, respectively.

Table 3. Estimation of the embedded pre-farm, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions of the farm system using the FarmGAS and Framework calculators

Source of GHG emission		FarmGAS		Framework	
		Home-bred ($t\ CO_2e$/annum)	Purchased ($t\ CO_2e$/annum)	Home-bred ($t\ CO_2e$/annum)	Purchased ($t\ CO_2e$/annum)
Embedded pre-farm	Purchased fodder & grain	10.0	10.9	10.0	10.9
	Fertilisers	23.9	25.9	23.9	25.9
Carbon dioxide	Electricity & fuel	15.0	16.2	15.0	16.2
Methane	Enteric fermentation	367.3	143.3	483.9	250.5
	Animal waste	0.1	< 0.1	0.1	< 0.1
Nitrous oxide	Animal waste	34.8	11.1	163.7	99.1
	N fertiliser	27.0	29.4	26.8	29.0
Enterprise total GHG emissions*		415.8	236.9	629.3	431.7
Enterprise dressed weight sold (kg)		34,630	37,614	34,630	37,614
Enterprise GHG emissions intensity (kg CO_2e/kg dressed weight)		12.0	6.3	18.2	11.5
Total farm GHG emissions ($t\ CO_2e$/annum)		652.8		1,062.5	
Total farm dressed weight sold (kg)		72,244		72,244	
Total farm GHG emissions intensity (kg CO_2e/kg dressed weight)		9.0		14.7	

* 87% of home-bred lamb enterprise GHG emissions allocated to meat production (Browne *et al.* 2011); 100% of purchased lamb enterprise GHG emissions allocated to meat production

2. Abatement strategies assessment

The result of seven abatement strategies on total GHG emissions and the GHG emissions intensity of are as follows:

1. *Ewe age at first mating- joining at 7 months of age as opposed to 19 months of age.*

The benefit of joining maiden ewes at 7 months of age compared to 19 months of age reduced total GHG emissions of the home-bred lamb enterprise by 75.6 t CO_2e/annum (Figure 4; with 19 month assessment shown as the strategy such that the difference between the baseline and the strategy columns is the improvement achieved with the farm already adopting this strategy). The GHG emissions intensity of lamb production decreased from 20.4 to 18.2 kg CO_2e/kg meat; equivalent to a 10.7% decline (Figure 5).

2. *Ewe longevity- increase mean ewe longevity from current 5.2 yrs to 6 yrs before culling*

This strategy reduced the total GHG emissions of the home-bred enterprise by 3.0t CO_2e/annum (Figure 4). While this strategy resulted in raising additional lambs, the increase in emissions associated with these additional lambs was less than the increase in GHG emissions associated with having a larger number of mature ewes present on the farm. The GHG emissions intensity of lamb production decreased from 18.2 to 17.4 kg CO_2e/kg meat; equivalent to a 4.1% decline (Figure 5).

3. *Ewe efficiency- reduce ewe live weight by 10% with no impact on lamb productivity*

This strategy reduced the total GHG emissions of the home-bred enterprise by 39.6 t CO_2e/annum (Figure 4). The GHG emissions intensity of lamb production decreased from 18.2 to 17.0 kg CO_2e/kg meat; equivalent to a 6.3% decline (Figure 5).

4. *Increase lamb weaning rates with no changes to other farm management aspects*

This strategy increased the total GHG emissions of the home-bred enterprise by 10.3 t CO_2e/annum due to the additional lambs weaned (Figure 4). However the additional lamb produced diluted this increase in total GHG emissions such that the GHG emissions intensity of lamb production decreased from 18.2 to 16.9 kg CO_2e/kg meat; equivalent to a 7.1% decline (Figure 5).

5. *Increase lamb weaning rates but maintain same number of weaned lambs by reducing ewe numbers*

This strategy reduced the total GHG emissions of the home-bred enterprise by 27.8 t CO_2e/annum (Figure 4). The GHG emissions intensity of lamb production decreased from 18.2 to 15.9 kg CO_2e/kg meat; equivalent to a 12.7% decline (Figure 5).

6. *Reduce lamb dietary crude protein*

This strategy reduced the total GHG emissions of the home-bred lamb enterprise by 20.1 t CO_2e/annum (Figure 4). The GHG emissions intensity of lamb production decreased from 18.2 to 17.6 kg CO_2e/kg meat; equivalent to a 3.2% decrease (Figure 5). Total enterprise GHG emissions for the purchased lamb enterprise decreased by 44.9 t CO_2e/annum with the adoption of this strategy. The GHG emissions intensity of lamb production decreased from 11.5 to 10.3 kg CO_2e/kg meat; equivalent to a 10.4% decline (data not shown).

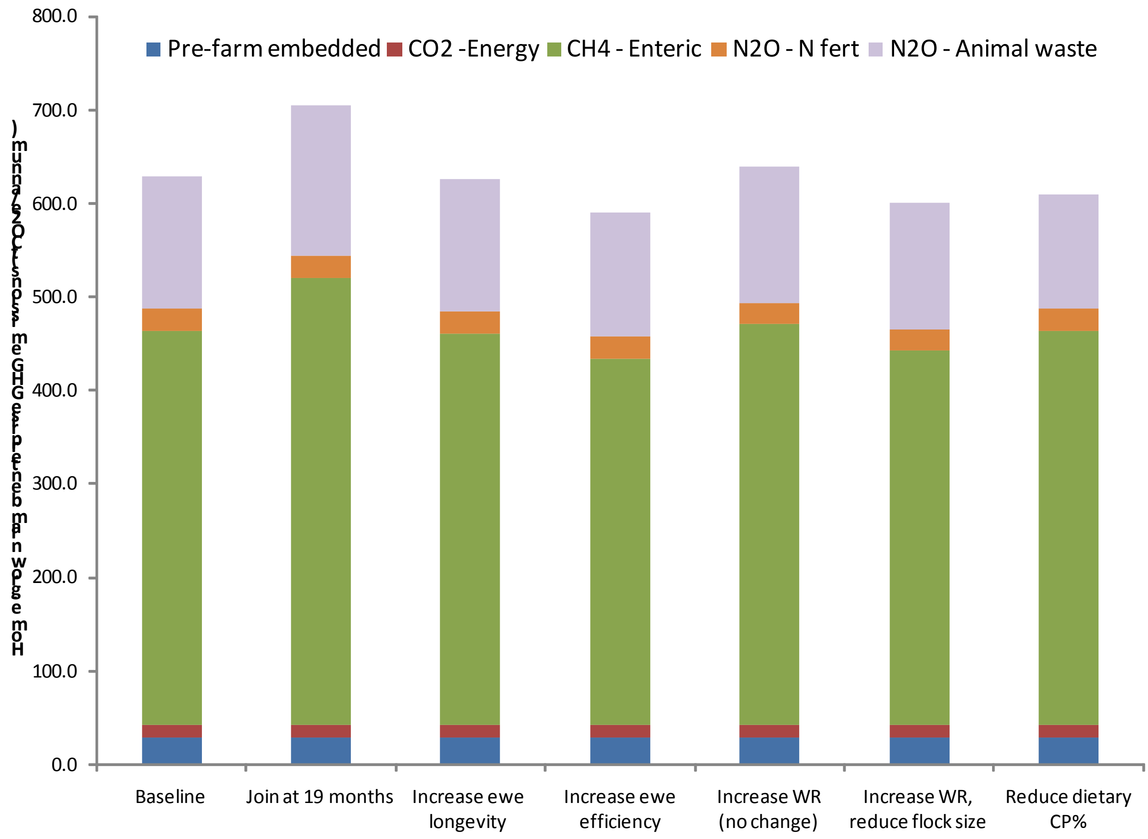

Figure 4. Pre-farm embedded, carbon dioxide (CO_2) - energy, methane (CH_4) - enteric and nitrous oxide (N_2O) - N fertiliser and animal waste emissions (t CO_2e/annum) for the baseline and six abatement strategies for the home-bred lamb enterprise (WR- weaning rate, CP- crude protein)

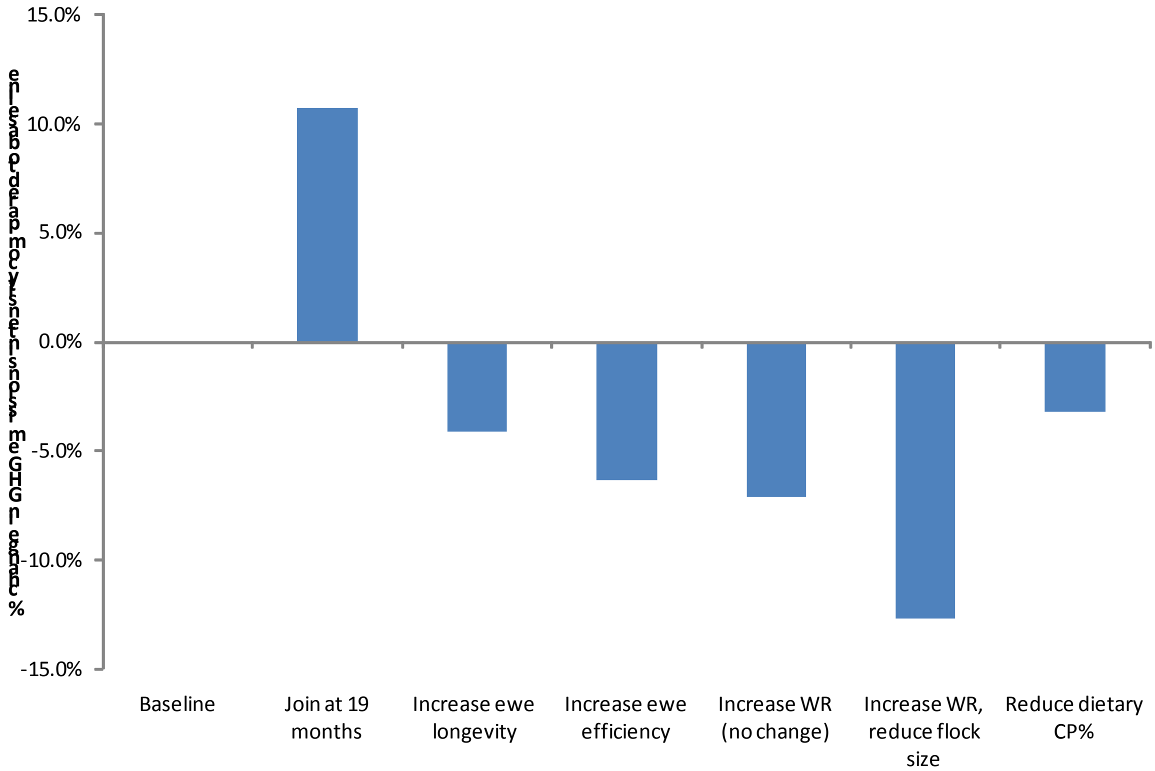

Figure 5. Percentage change in the greenhouse gas emissions intensity of lamb production for six abatement strategies compared to the baseline home-bred lamb enterprise (WR- weaning rate (lambs/ewe), CP- crude protein)

7. Lamb growth rates

Due to the methodology and equations in the Framework calculator, where daily live weight gain (LWG) are not directly linked to enteric CH_4 emission estimations, and given that enteric CH_4 emissions are the biggest single source of emissions, this strategy was assessed differently to the previous six abatement strategies.

The baseline home-bred lamb enterprise required on average 195 days to reach a target live weight of 50kg for slaughter; equivalent to an average daily LWG of 0.24 kg/day. This equated to an estimation of 94.3 kg $CO2_e$ of enteric CH_4 per lamb (0.48kg CO_2e/day; Table 4). Increasing LWG by 0.03 kg/day, such that the target live weight was achieved 20 days sooner, required lambs to have a daily intake of 1.22 kg DM/day; an increase of 0.08kg DM/day from the baseline. The enteric CH_4 emission per lamb associated with a higher LWG was 90.0 kg CO_2e (0.51kg CO_2e/day). Although increasing daily LWG by 0.03 kg/day increased daily enteric CH_4 emissions per lamb, the GHG emissions intensity of lamb production decreased by 0.2 kg CO_2e/kg dressed weight; equivalent to a 4.5% reduction in enteric CH_4 emissions/ kg dressed weight (Table 4).

The baseline purchased lamb enterprise required on average 90 days to reach target live weight for slaughter, on average a 15.3 kg LWG. This equates to an average daily LWG of 0.17 kg/day, with each lamb emitting 36.7 kg CO_2e as enteric CH_4 (0.41 kg CO_2e/day; Table

4). Increasing daily LWG by 0.02 kg/day, such that the target live weight was achieved 10 days sooner, required lambs to have a daily intake of 1.01 kg DM/day; an increase of 0.06kg DM/day from the baseline. The enteric CH_4 emissions per lamb associated with a higher LWG was 34.6 kg CO_2e (0.43 kg CO_2e/day). Although increasing daily LWG by 0.02 kg/day increased daily enteric CH_4 emission per lamb, the GHG emissions intensity of lamb production decreased by 0.3 kg CO_2e/kg dressed weight; equivalent to a 5.8% reduction in enteric CH_4 emissions per unit of meat production (Table 4).

Table 4. Influence of increasing daily growth rates on total carbon dioxide equivalents from enteric methane production and the carbon dioxide equivalents emissions from enteric methane production per kg of dressed weight for the home-bred and purchased lamb enterprises (LWG- live weight gain)

	Home-bred		Purchased	
	Baseline	Strategy	Baseline	Strategy
Mean live weight gain target (kg/lamb)	46.0	46.0	15.3	15.3
Time to achieve live weight gain (number of days)	195	175	90	80
Daily live weight gain (kg/day)	0.24	0.26	0.17	0.19
Daily energy requirements to achieve target LWG * (MJ; ME per day)	12.5	13.4	10.4	11.1
Daily dry matter intake[†] (kg DM/day)	1.14	1.22	0.95	1.01
Daily CH_4 emissions[‡] (kg CH_4/day)	0.023	0.025	0.019	0.021
Enteric CH_4 emissions to achieve target weight (kg CH_4/lamb)	4.49	4.29	1.75	1.65
CO_2e emissions from enteric CH_4 to achieve target weight (kg CO_2e/lamb)	94.3	90.0	36.7	34.6
CO_2e emissions intensity from enteric CH_4 to achieve target weight (kg CO_2e/kg dressed weight)	4.2	4.0	5.3	5.0
% change from baseline	n/a	4.5	n/a	5.8

***** Daily energy requirement based on 5 MJ energy/day for maintenance and 3.2MJ energy /100g live weight gain (McDonald *et al.* 1995)

[†] Daily dry matter intake based on 11MJ/ kg dry matter (equivalent to the 75% DMD diet for the home-bred lamb enterprise)

[‡] Daily methane emissions calculated as intake (kg DM/day) x 0.0188 + 0.00158 (DCCEE 2009)

3. Strengths and weaknesses of the various calculators and models

The applications of inventory GHG calculators are in many ways quite different to biophysical simulation models. The two inventory calculators adopted in this study (FarmGas and the Framework calculator) can be used to estimate the whole of farm system GHG emissions. In contrast, most biophysical models are only able to estimate the GHG emissions from a limited number of sources within the farm system. Inventory calculators often follow IPCC-compliant methodologies which in many instances, biophysical models do not. However, inventory calculators fail to capture the dynamic interactions between emissions sources, climate, soil, and management. The strengths and weaknesses of the two inventory calculators and two biophysical models (GrassGro and SGS) in modelling the lamb production enterprises of the current study are provided in Table 5.. It is important to note at the time of submitting this report, the developers of FarmGas were undertaking significant alterations to FarmGas which could either minimise or eliminate some of the weaknesses we encountered with the FarmGas calculator.

Table 5 Strengths and weakness of the two inventory calculators (FarmGas and Framework) and the two biophysical simulation models (GrassGro and SGS) for estimating GHG emissions.

	FarmGas calculator	Framework calculator
Strengths	o Follows IPCC and Australian inventory methodology and emission factors o Seasonal births, purchases and sales can be entered allowing for stock movements to be easily captured in association with accurate representation of seasonal stock numbers o Estimates stock CH_4 emissions from both enteric fermentation and manure management o Estimates direct and indirect N_2O emissions from animal waste management and N fertiliser applications	o Follows IPCC and Australian inventory methodology and emission factors o Allows for user defined seasonal live weight, live weight gain, feed availability and feed quality values o Allows for users defined commencement date such that the assessment period can commence in any season o Estimates stock CH_4 emissions from both enteric fermentation and manure management o Estimates direct and indirect N_2O emissions from waste management and N fertiliser applications o Estimates CO_2 emissions from electricity and fuel consumption o Excel based for improved accessibility o Allows for the exploration of abatement strategies that include changes to feed quality and feed availability o Able to model a purchased trade lamb enterprise in isolation to any other sheep enterprise
Weaknesses	o Uses state-based average values for live weight, live weight gain, feed availability and feed quality as opposed to farm-specific data o Commencement period is predefined as beginning in spring and cannot be altered irrespective of when the assessment period begins o No estimation of CO_2 emissions associated with electricity and fuel consumption o Unable to investigate abatement strategies involving improvements in diet quality and feed availability o Has a single factor emission factor for estimating N_2O emissions from N fertiliser applications irrespective of soil type, fertiliser rate/ source and climatic conditions o No feedback mechanism to verify that the production figures provided, in this instance lamb produced in a given period of time, is possible based on the feed quality, feed availability and feed intake estimations of the calculator. Having user defined seasonal feed quality and feed availability fugues would allow for this o Web-based so accessibility is limited compared to other tools o Can only model a 12 month period with the commencement period set to occur in spring only	o User needs to define average seasonal stock numbers based on births, purchases and sales o Can only model a 12 month period but this can start in any month/season o Has a single factor emission factor for estimating N_2O emissions from N fertiliser applications irrespective of soil type, fertiliser rate/ source and climatic conditions o No feedback mechanism to verify that lamb live weight gain figures provided, is possible based on feed quality, feed availability and feed intakes

	GrassGro model	SGS pasture model
Strengths	o *Uses site-specific soil and climatic data to predict seasonal pasture production and its influence on animal production* o *Can model varying farm stock enterprises (i.e. a beef herd and sheep flock) including a purchased trade lamb enterprise* o *Ability to explore various management abatement strategies (e.g. altered lambing dates) and their influence on animal production and associated enteric CH_4 emissions* o *Feedback mechanism to ascertain that livestock production is achievable from feed quality and availability, with the ability to introduce supplementary feed when home-grown feed supply is limited* o *Can model multiple perennial and annual pasture species on multiple paddocks with varying soil types* o *Has extensive library of default livestock enterprises, soil parameters, pasture species that can be copied and adapted to suit the farm enterprise under investigation* o *Import/export various farm systems, soil parameters and stock dynamics between users* o *Extensive results output which can be tailored as required* o *Simulations can be undertaken over multiple years to ascertain the impact of changing climatic conditions on pasture supply and stock production*	o *Uses site-specific soil and climatic data to predict seasonal pasture production and its influence on animal production* o *Estimation of enteric CH_4 emissions although it uses a different methodology to the inventory calculators, this is still an accepted IPCC methodology for estimating enteric CH_4 emissions (based on 6% gross energy intake for forages and 4% gross energy intake of concentrates)* o *Estimation of direct and indirect N_2O emissions from dung and urine deposition* o *Model multiple paddocks with varying perennial and annual pasture species with varying soil types* o *Ability to simulate the influence of varying N fertiliser rates/source and the associated soil-based N_2O emissions* o *Ability to simulate varying irrigation regimes* o *Feedback mechanism to ascertain that livestock production is achievable from feed quality and availability, with the ability to introduce supplementary feed when home-grown feed supply is limited* o *Available (free) after contacting developer to gain registration code*
Weaknesses	o *Does not conform to IPCC and National inventory methodology and emission factors* o *Predicts enteric CH_4 emissions only; no estimation of CH_4/N_2O emissions from animal dung and urine deposition, N_2O emissions associated with N fertiliser applications* o *Carbon dioxide emissions from electricity and fuel consumption are not provided* o *Can only simulate a rain-fed farm system; irrigation is currently not possible* o *Application of synthetic N fertilisers within the model is currently not possible and as such it is not possible to assess the impact of varying N fertiliser practices on soil-based N_2O emissions* o *Difficult to model complex farm systems as shown in this study due to the complexity of stock dynamics (e.g. multiple mobs of lambs rotated around paddocks as required). However, this model has been used to successfully model less complex farm systems* o *Complex data entry required* o *Available (at cost) from the distributor*	o *Uses non-IPCC and National inventory methodology for estimating N_2O emissions* o *Unable to model a purchased trade lamb enterprise; only possible to model a ewe with lamb enterprise or a wether enterprise* o *Difficult to model complex farm systems as shown in this study due to the complexity of stock dynamics (e.g. multiple mobs of lambs rotated around paddocks as required). However, this model has been used to successfully model less complex farm systems* o *Removal of lambs from the farm system is based on reaching a target date as opposed to a target weight* o *Currently not possible to simulate the growth of annual forage annual crops (e.g. forage brassicas). However a generic crop option is considered most likely in future releases of the model*

While the two biophysical models appear limited in estimating whole farm GHG emissions, both models have excellent capacity to examine the influences of various climatic and management practices may have on feed availability, supplementary feed requirements and in the case of the SGS pasture model, the dynamic nature of urine, dung and N fertiliser N_2O emissions. For example, in this study the SGS pasture model was used to provide a simulated estimate of monthly pasture growth rates for a rain-fed perennial ryegrass pastures based on historical climatic data (1970 to 2010) for the region (Figure 6). This location exhibited substantial variation in monthly growth rates and inter-annual pasture production. While the mean annual pasture production was 7.4 t DM/ha.annum, pasture production during the simulation period ranged between 3.7 and 12.6 t DM/ha.annum. The farm in the current study substantially minimises the impact of climate variability on inter annual pasture production through the adoption of irrigation and the inclusion of annual forages within the feedbase. In addition, the farm business is structured to vary the volume of lambs purchased each year as feed supply alters due to climatic conditions.

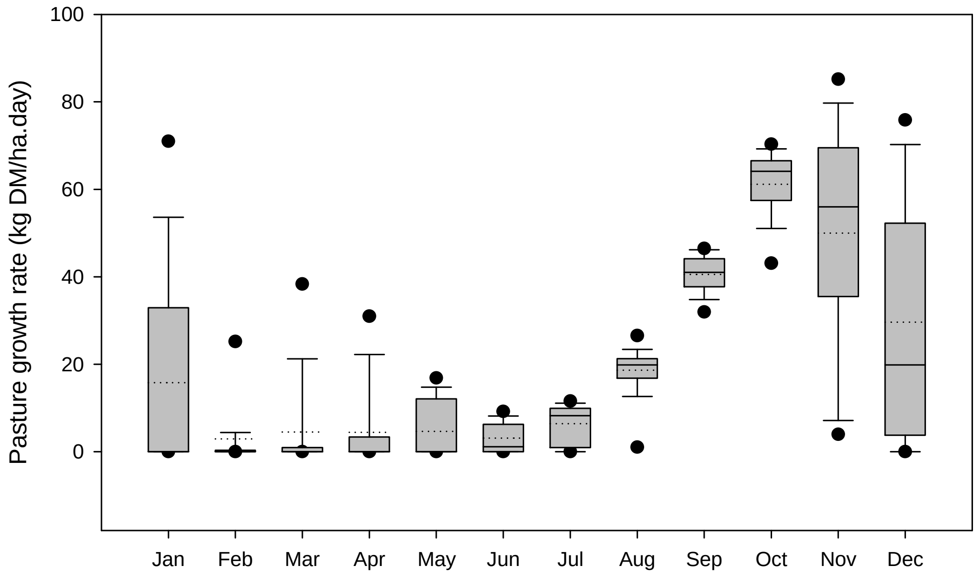

Figure 6. Box plot graph (5th, 10th, 25th, 50th, 75th, 90th, and 95th percentile, with dotted mean line) showing the variability in monthly pasture growth rates for a Cressy rain-fed perennial ryegrass pasture.

The Framework calculator was selected as being the most suitable tool for examining the baseline GHG emissions of both lamb enterprises and for examining the effect of varying abatement strategies. However, the Framework calculator does have some limitations that could be overcome by assessing the farm system in a biophysical model and then importing the outputs from the biophysical model into the inventory calculator. This process was explored by Browne *et al.* (2011) where they modelled a sheep enterprise in GrassGro and used the outputs from GrassGro to inform the stock dynamics in the Framework calculator. Identifying which aspect of the farming system that is being explored to reduce GHG emissions and then selecting the tool that best reflects this aspect of farm system will always be the preferred modelling option.

4. Stochastic uncertainty assessment

Monte Carlo statistic uncertainty assessment indicated that there is a 90% probability that the GHG emissions intensity of lamb production for the home-bred lamb enterprise would be between 19.42 and 28.41 kg CO_2e/kg dressed weight, with a mean ± standard deviation of 23.53 ± 2.77 kg CO_2e/kg dressed weight (Figure 7).

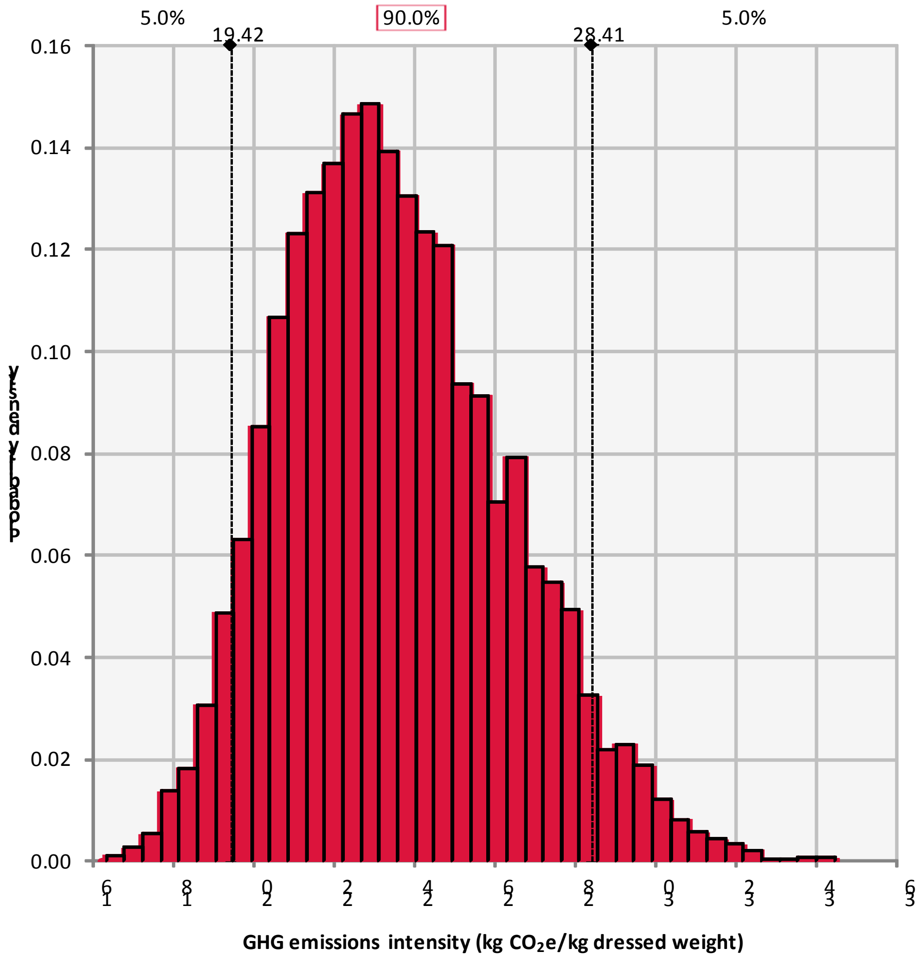

Figure 7. Probability density histogram of the greenhouse gas emissions intensity of lamb production (kg CO_2e/kg dressed weight) for the home-bred lamb enterprise based on a Monte Carlo stochastic uncertainty assessment

The effect of changing each input risk variable (in this instance the emission factors listed in Table 2) by 1 standard deviation value has on the output variable (in this instance the GHG emissions intensity of lamb production) is shown as a standardised regression co-efficient value (Figure 8) and a mapped value (Figure 9). A standardised regression co-efficient value shows the change in value as a co-efficient (proportion) of the standard deviation of the output variable, i.e. the amount, as a proportion of the standard deviation, that the GHG emissions intensity of lamb production, will changes in response to a 1 standard deviation change in the input risk variable. By multiplying the standardised regression co-efficient by the standard deviation of the GHG emissions intensity of lamb production, the absolute change in the GHG emissions intensity in response to a 1 standard deviation change in the input risk variable is produced (Figure 9). For example, changing the direct N_2O-urine emissions by 1 standard deviation would increase the absolute GHG emissions intensity of lamb production by 2.10 kg CO_2e/kg dressed weight (i.e. 0.76 x 2.77 = 2.10), where the regression coefficient value of direct N_2O-urine emissions was 0.76 and the standard deviation for the GHG emissions intensity of lamb production is 2.77 kg CO_2e/kg dressed weight. As would be expected, all the regression coefficient values were positive. These ranged between 0.01 for direct N_2O emissions from N fertiliser applied to crops, and 0.76 for direct N_2O emissions from urine excretion), highlighting that the uncertainty associated with N_2O emissions from urine depositions has a very strong influences on emissions variability whilst the uncertainty associated with direct N_2O emissions from N fertilisers has little influence.

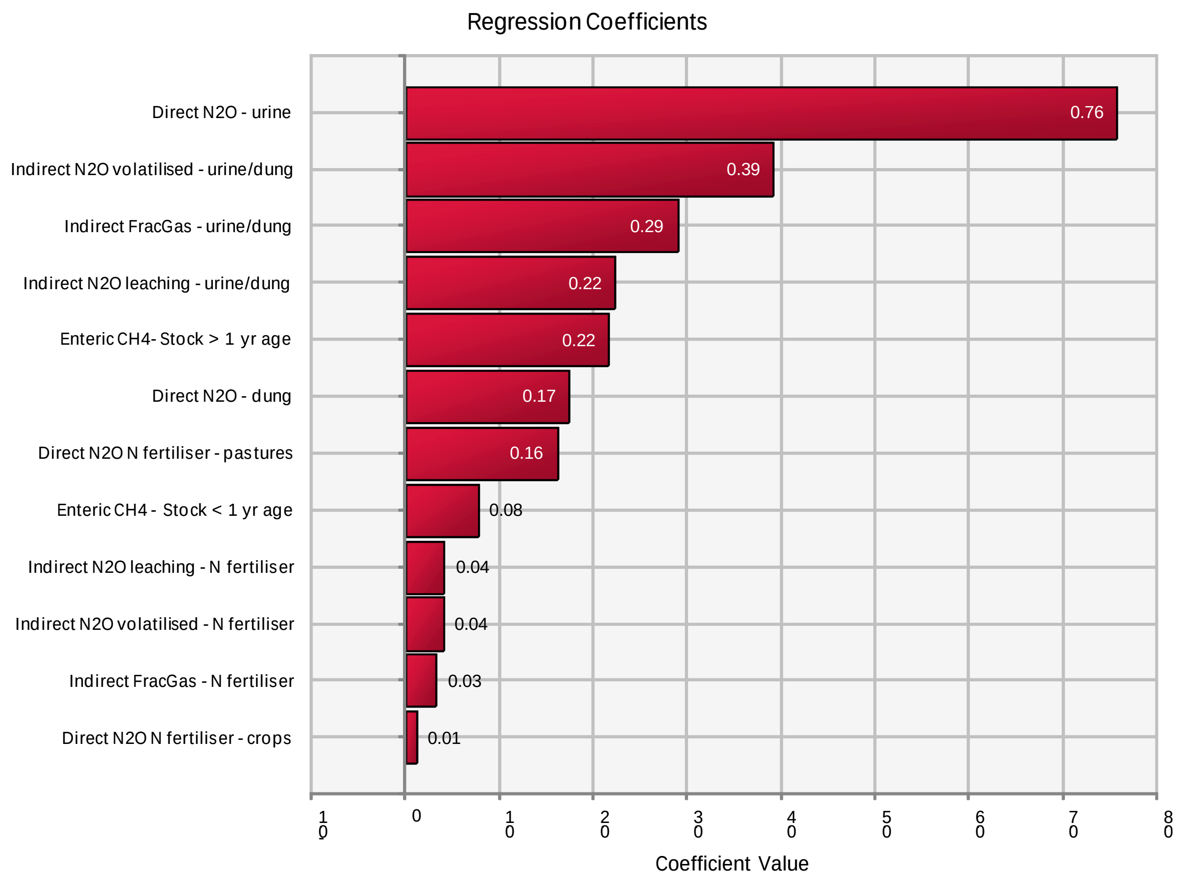

Figure 8. Standardised regression coefficient values for each emission factor contributing to the greenhouse gas emissions intensity of lamb production (kg CO_2e/kg dressed weight) for the home-bred lamb enterprise

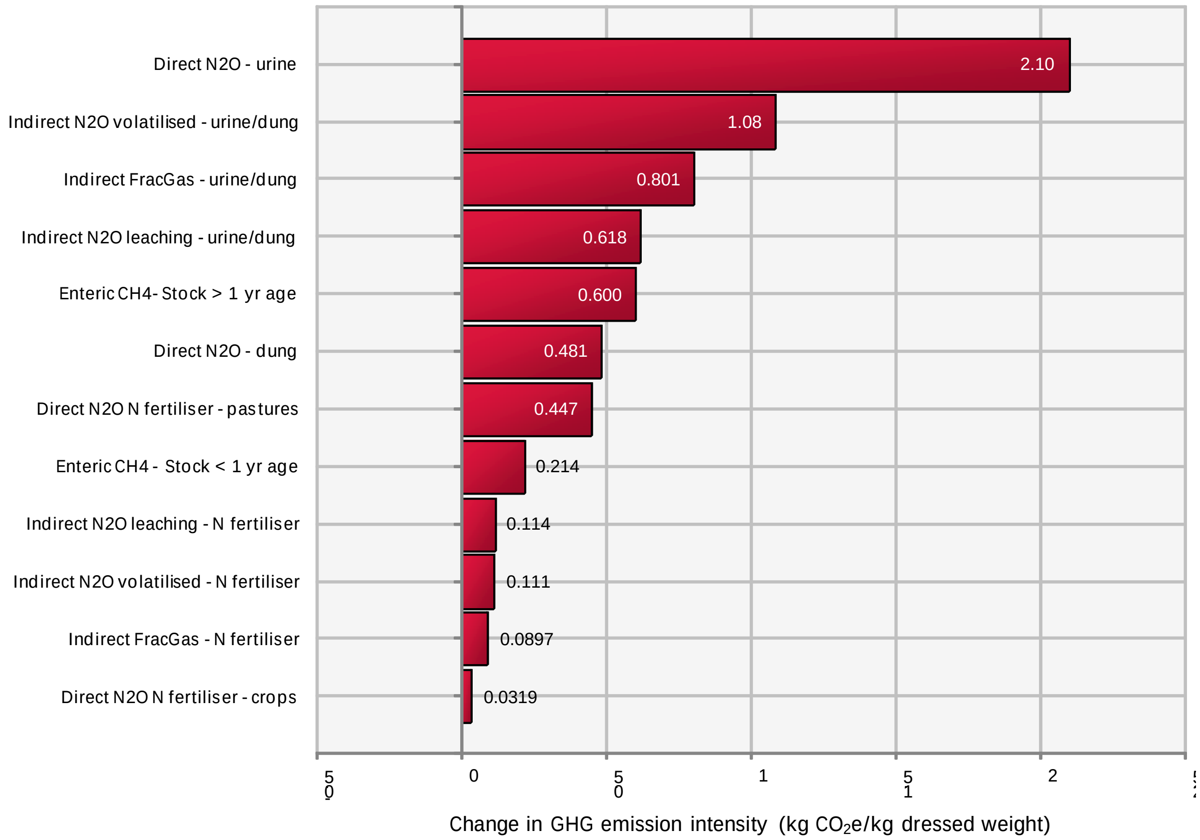

Figure 9. Change in absolute greenhouse gas emissions intensity of lamb production (kg CO_2e/kg dressed weight) when increasing each emission factor variable by one standard deviation for the home-bred lamb enterprise

Monte Carlo statistic uncertainty assessment indicated that there is a 90% probability that the GHG emissions intensity of lamb production for the purchased lamb enterprise would fall between 10.87 and 16.96 kg CO_2e/kg dressed weight, with a mean ± standard deviation of 13.69 ± 1.88 kg CO_2e/kg dressed weight (Figure 10). Figure 11 presents the standardised regression co-efficient for each emission factor, showing that all regression coefficient values were positive and ranged between 0.02 and 0.74. The result of this was an absolute change in the GHG emissions intensity of lamb production for the purchased lamb enterprise of between 0.04 and 1.39 kg CO_2e/kg dressed weight when altering each emission factor variable by one standard deviation (Figure 12).

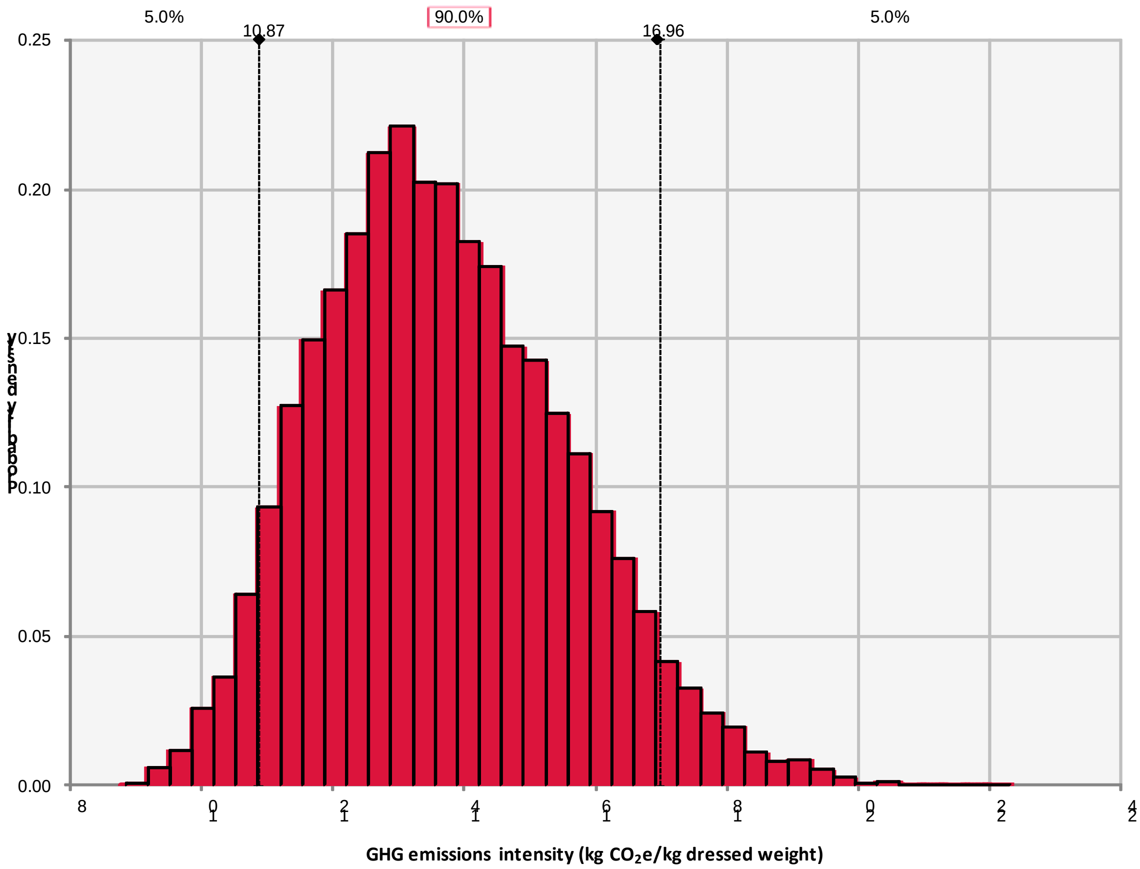

Figure 10. Probability density histogram of the greenhouse gas emissions intensity of lamb production (kg CO_2e/kg dressed weight) for the purchased lamb enterprise based on a Monte Carlo stochastic uncertainty assessment

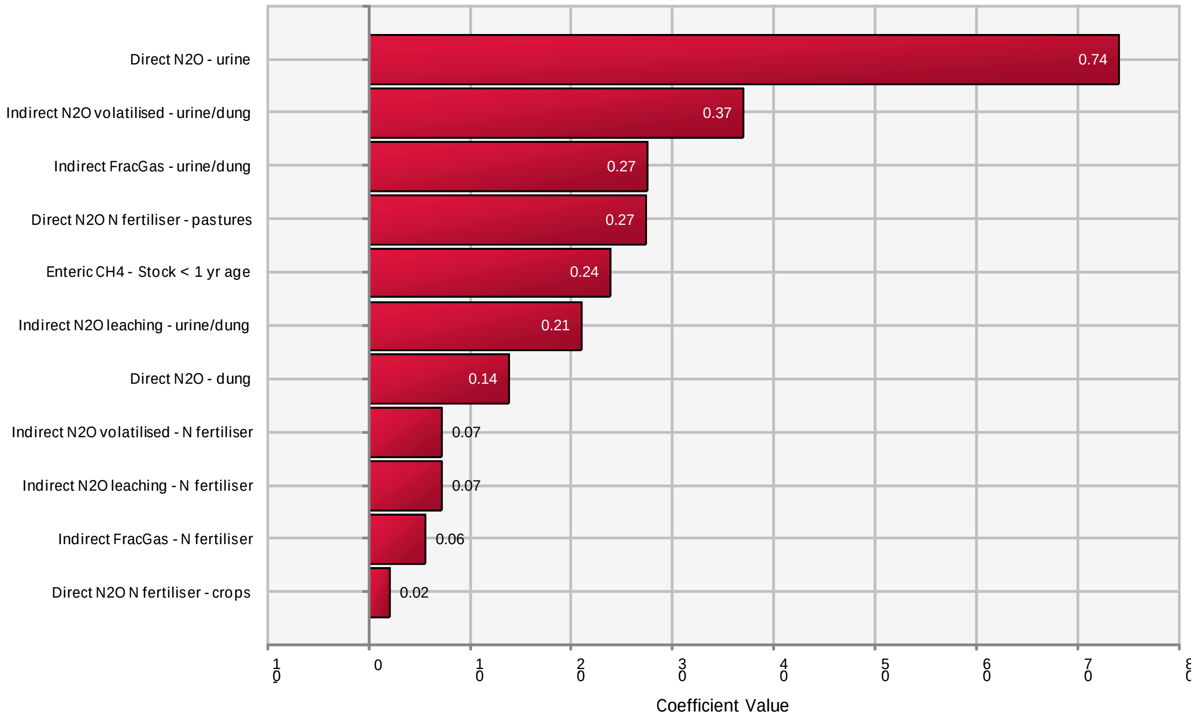

Figure 11. Standardised regression coefficient values for each emission factor contributing to the greenhouse gas emissions intensity of lamb production (kg CO_2e/kg dressed weight) for the purchased lamb enterprise

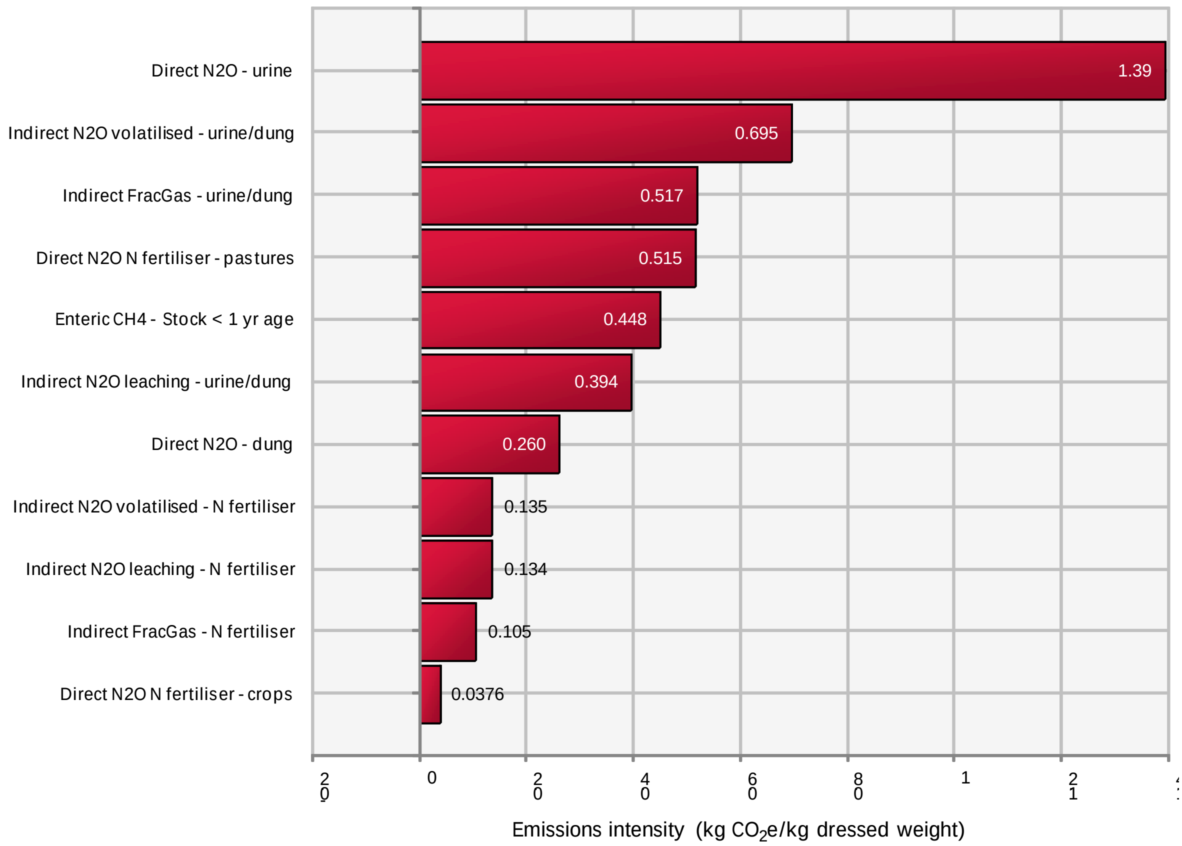

Figure 12. Change in absolute greenhouse gas emissions intensity of lamb production (kg CO_2e/kg dressed weight) when increasing each emission factor variable by one standard deviation for the purchased lamb enterprise

Discussion/ Conclusions

A review of literature has highlighted that there has been few studies undertaken within Australia that have estimated the GHG emission intensity of lamb production and of those that have been undertaken, they are related to home-bred lamb enterprises. No cited studies could be found that estimated the GHG emissions of a trade purchased lamb enterprise similar to the purchased lamb enterprise in this study.

Alcock and Hegarty (2011) created several hypothetical lamb enterprises in GrassGro, where only enteric CH_4 emissions were estimated. They reported the enteric CH_4 emissions to be 5.49 and 5.01 kg CO_2e/kg live weight for a cross-bred lamb enterprise sold at 44 and 53 kg live weight, respectively. In comparison, this study found that the GHG emissions from enteric CH_4 was 4.15 and 6.31 CO_2e/kg live weight for the home-bred lamb enterprise using FarmGas and the Framework calculators, respectively. Browne *et al.* (2011) explored a simulated hypothetical prime lamb enterprise in GrassGro to define the livestock system and then imported the model outputs into the Framework calculator to estimate the on-farm CH_4 and N_2O emissions. The GHG emissions intensity of lamb production was estimated at 11.4 kg CO_2e/kg dressed weight. While the results from this study using FarmGas was comparative, at 10.1kg CO_2e/kg dressed weight, it was substantially lower than the Framework estimation of 16.3 kg CO_2e/kg dressed weight. Peters *et al.* (2010), using the national methodology estimated GHG emissions intensity to be 8.3 and 7.2 kg CO_2e/kg hot carcass weight for a sheepmeat supply chain in Western Australia for two varying years.

The variability of results from this and other cited studies highlights the difficulty in comparing results where different methodologies, assumptions, definitions of boundaries and emission factors can be used (Crosson *et al.* 2011). Examples of this include:

a. Varying global warming potential (i.e. the potential of CH_4 or N_2O to warm the environment compared to CO_2). For example using of 25 compared to 21 for CH_4 as per the Alcock and Hegarty (2011) study;
b. Varying values for diet quality, lambing rates, stock live weights and daily diet intakes all could have contributed to the differences in results between Browne *et al.* (2011) and this study;
c. Differences in system boundaries. The Peters *et al.* (2010) study defined the system boundary as being post-slaughter, and included additional pre-farm embedded emissions such as pesticides and soil modifiers. While the additional pre-farm embedded emissions may have contributed only a small amount of additional GHG emissions, including meat processing was substantial at approximately 13% of the total carbon footprint.

The GHG emissions from embedded pre-farm, energy consumption and N fertilisers were allocated based on the proportion of dressed weight sold from each enterprise given the difficulty in accurately determining what percentage of grain, as an example, was fed to each lamb enterprise. Therefore the two calculators were in agreement in terms of GHG emissions for these embedded pre-farm sources. The only exception to this was a slight difference between the two calculators in terms of N_2O emissions from N fertilisers. In FarmGas, all N fertiliser was assumed to be applied to pastures, with an emission factor of 0.4% (DCCEE 2009). In the Framework calculator, a percentage of fertiliser was applied to crops, with an emission factor of 0.3% (DCCEE 2009). These two emission factors resulted in a slightly reduced N_2O emission from N fertilisers with the Framework calculator compared to FarmGas. In addition, CH_4 emissions from animal waste were negligible, irrespective of which calculators or enterprises were assessed. The two sources of differentiation between calculators were GHG emissions from enteric CH_4 and N_2O from animal waste, with the Framework calculator estimating substantially higher GHG emissions than FarmGas.

The home-bred and purchased lamb enterprise emissions were 1.5 and 1.8 times higher, when using the Framework calculator compared to FarmGas. The two calculators use the same national inventory and as such the algorithms and emission factors are essentially the same. However, FarmGas automatically defines some data entry based on the location of the farm under investigation. State-based figures are used for live weight and live weight gain for lambs, diet quality (DMD% and CP %) and feed availability (t DM/ha). These state-based factors are an average for the whole state, irrespective of individual farm management practices such as forage species, fertiliser and irrigation inputs. Feed quality for the farm in this study was significantly higher than the default state-based figures, with the lamb's diet DMD at 75% compared to the Tasmanian state default of 66.75% and CP at 24% compared to the state default of 14.25%.

Daily intake estimations are a function of feed quality with a positive correlation with increases in diet DMD%. As shown by the abatement strategy assessment of increasing live weight gain, increases in daily intakes result in an associated increase in enteric CH_4 emissions per day. Using the state based default values in FarmGas resulted in the reverse of this, a lower digestibly figure which corresponds with a lower daily intake and as such a lower daily CH_4 emission. Based on the daily intake and feed quality used in the FarmGas it would not have been possible to achieve the daily live weight gain reported for this farm in the current study. As such the Framework calculator is considered as the most appropriate tools for estimating enteric CH_4 emissions. It is important to note that both calculators fail to provide a check that the specified live weight gain is achievable from the estimated dietary intakes.

Similarly increases in the crude protein concentration of the diet result in increases in the amount of N excreted in dung and urine, thus increasing N_2O emissions from animal waste. This was best illustrated when implementing the abatement strategy of reducing the CP% of the purchased lamb enterprise from 24 to 14%. Nitrous oxide emissions were reduced by 44.9 t CO_2e/annum; equating to a 10.4% reduction in total enterprise emissions. However, there was a nine-fold difference (99.1 compared to 11.1 t CO_2e/annum) in N_2O animal waste emissions between the two calculators when assessing the purchased lamb enterprise (Table 3). While the differences in feed quality figures explain some of this difference, the associated difference in animal intake would have also contributed to this. In addition to the inability to define actual feed quality figures with FarmGas, the inability to correctly allocate stock numbers to their corresponding season within FarmGas is also considered a limitation to the calculator. It is envisage that these limitations will be addressed in the most recent version of FarmGas.

We were unable to model the trade lamb enterprise in isolation to the home-bred lamb enterprise in FarmGas. Not being able to commence the assessment year with no stock present created an error within the calculator. To overcome this, the two enterprises were assessed together with the difference between the combined enterprises and the home-bred enterprises equating to the purchased lamb enterprise emissions. Therefore, although the purchased lamb enterprise did not commence until December 2010, we needed to assume it started in spring in FarmGas to allow all the births, purchases and sales of lambs from both enterprises to be condensed into a 12 month period. The result of this compromise was that within the FarmGas calculator, lambs were purchased in spring when in reality they were not purchased until summer.

The ultimate abatement strategy for reducing GHG emissions per unit of meat production is to increase the ratio of livestock ‘production’ to ‘maintenance’ (Johnson and Johnson 1995; Monteny *et al.* 2006; Clark *et al.* 2007). The strategy of increasing the weaning rate combined with reducing ewe numbers to maintain the same number of weaned lambs resulted in the greatest reduction in the GHG emissions intensity of lamb production from all the strategies explored in this study.

This study also explored the benefits of increasing the weaning rate by an absolute of 10%. This was achieved firstly by increasing lamb numbers without changes to any other management practice. Increasing the number of lambs increased enteric CH_4 emissions by 1.7%. However, the additional meat produced diluted these additional emissions such that the CH_4 emissions intensity declined 7.0%. This is comparative to the results of Cruickshank *et al.* (2009) where they found that increasing the scanning rate by 10% reduced enteric CH4 emissions by 7.8%. The second approach to exploring the benefits of increasing weaning rates involved maintaining the same number of lambs sold as for the baseline enterprise but from fewer ewes. Reducing ewe numbers reduced total GHG emissions and given the same number of lambs was sold, enteric CH_4 emissions intensity declined by 13.2%. For both options we assumed that ewe longevity remained at on average 5.2 years to be the same as the baseline enterprise. However, it is possible that with increased weaning rates, there could be an increase in deaths and/or culling due to added pressure on the flock. This would then require an increase in the number of replacement ewes required to retain a similar amount of lamb meat being sold. This strategy would be best assessed across years using a biophysical model in combination with an inventory calculator.

Management or genetic factors that improve the rate at which lambs reach target live weights earlier will improve not only the total enterprise GHG emissions but also the GHG emissions intensity of lamb production. Joining ewe lambs at 7 months of age as opposed to 19 months of age reduces the duration that unproductive animals are present on farm.

This farm already joins at 7 months of age so by modelling the strategy of having an additional 285 unproductive maiden ewes and comparing the difference with the strategy and the baseline, this provided an indication of the level of abatement already being achieved. Enteric CH_4 emissions were reduced by 12.0% and this was comparable to the 13.0% reduction achieved with this strategy reported by Cruickshank *et al.* (2009). However, in contrast to this, when Alcock and Hegarty (2011) modelled this strategy for 2^{nd} cross lamb production, with replacement ewes purchased 2 weeks prior to mating, they found that the GHG emissions intensity of lamb production (sum of CH_4 and N_2O only) increased by between 3 and 9% compared to this study showing that this strategy reduced the GHG emissions intensity of lamb production from CH_4 and N_2O emissions by 11.4%. One potential reason for this contrast in results could be that for the Alcock and Hegarty (2011) study, the authors suggested that joining maiden ewes at 7 months of age would result in fewer lambs from these maiden ewes due to lower weaning rates when compared to joining at 19 months of age. In this current study the same weaning rate was maintained irrespective of whether the maiden ewes were mated at 7 or 19 months of age. In addition to this, in the current study we maintained replacement ewe lambs on-farm for their lifetime prior to joining, not only for 2 weeks prior to joining as per the Alcock and Hegarty (2011) study.

Other management or genetic factors that reduced enteric CH_4 emissions, either as a total or as emissions intensity, included improving ewe efficiency and increasing ewe longevity. These abatement strategies were shown to reduce emissions intensity by 6.9% and 4.1%, respectively. The results from this study were comparative to the Cruickshank *et al.* (2009) study where they found reducing ewe weight by 10% reduced enteric CH_4 emissions intensity by 3.9% and increasing the average cull age from 5 to 6 years reduced enteric CH_4 emissions intensity by 6.4%.

Exploring the influence of increasing the daily live weight gain to reach target live weight for slaughter sooner, highlighted the important interactions between diet quality, daily feed intakes and enteric CH_4 emissions. The FarmGas calculator assumes that diet quality varies throughout the year to give an annual average DMD of 66.75%. If the home-bred lambs had consumed a diet this low in digestibility year round, their daily intakes and daily enteric CH_4 emissions would have been reduced by approximately 39 and 22%, respectively. However, the lambs would have required, on average, 315 days to reach target live weight, thus increasing the GHG emissions intensity of lamb production from 15.9 to 20.5 kg CO_2e/kg dressed weight. Currently with FarmGas, the time period and live weight production are defined according to farm practise and this combined with lower daily enteric CH_4 emissions from the state-based default feed quality figures result in an underestimation of emission intensity. For future assessments of farm GHG emissions, with the purpose of these assessments being used as part of a monitoring and validation process for a carbon credit system, it is critical that farm-specific data is used, as opposed to state-based averages; otherwise errors in emission assessments will be inevitable.

Most strategies in this study were explored using the Framework calculator and as such, other components may have not been considered. Using a biophysical model such as

GrassGro could provide the ability to further explore the implications of changing one aspect could have on the overall outcome of the farming system. These aspects could include changes to lambing date, changes to species selection or the benefit of introducing supplementary feeding to achieve targets weights more rapidly. For example, Alcock and Hegarty (2011) examined the impact of feeding supplements when green herbage mass was restricted to less than 800kg DM/ha due to seasonal conditions and found that the GHG emissions intensity could be reduced by between 16 and 24% as a consequence of lambs reaching sale weight sooner.

The estimation of N_2O emissions from dung, urine and N fertilisers are in most instances based on a single default emission factor. While this single factor has been based on many long-term studies (de Klein *et al.* 2001), it is still only a single factor and as such does not take into consideration factors that influence N_2O emissions. These factors include soil type, climatic conditions, and in the case of N fertilisers, rate, source and timing of fertiliser applications. The benefit of biophysical models such as the SGS model is that this inventory approach of a very prescriptive single factor is replaced with a dynamic approach where the interactions between these factors are simulated. This is very important given that research has shown the N_2O emissions from urine, dung and N fertilisers can be quite variable (Oenema *et al.* 1997; Dalal *et al.* 2003; de Klein and Eckard 2008).

We did not model either the baseline lamb enterprises or their subsequent abatement strategies in either GrassGro or the SGS pasture model due to the difficulty in reflecting the diversity of forage species and stock dynamics that this farm exhibits. The SGS pasture model is not structured to model a purchased lamb enterprise; it can only model a ewe with lamb or a wether enterprise.

The GrassGro model was not used to assess the GHG emissions profile for either lamb enterprise. Although GrassGro estimates enteric CH_4 emissions, it is not possible to capture changes to non-CH_4 emissions with GrassGro, particularly those related to N_2O emissions. Nitrogen fertiliser applications and irrigation practices are not able to be simulated within GrassGro. Although modelling this complex enterprise was considered impractical within the current available biophysical models, these models have been used successfully used to explore less complex systems (Lodge *et al.* 2001, 2009; Badgery *et al.* 2010; Browne *et al.* 2011; Alcock and Hegarty 2011).

The purchased lamb enterprise was found to have a discernibly lower emission intensity of lamb production than the home-bred lamb enterprise. These purchased lambs came onto the farm in a similar manner to other resources such as fertiliser and grain. However, unlike these other resources, in this study we did not consider the emissions associated with raising these lambs prior to entering this farm's boundary. Some of the purchased lambs came from interstate, incurring additional emissions associated with transportation. Therefore while the GHG emissions intensity of lamb production was substantially lower for the purchased lamb enterprise compared to the home-bred lamb enterprise, it is difficult to compare the outcomes of these two enterprises. In addition, few studies have explored a finishing lamb enterprise in isolation to a ewe with lamb enterprise. However, studies of beef finishing enterprises (Phetteplace *et al.* 2001; Beauchemin *et al.* 2010; Eady *et al.* 2011) have been undertaken, with the consensus that the cow and calf phase contributes the largest proportion of total GHG emissions from beef production compared to the growing and finishing phase which accounts for a relatively small fraction of total GHG emissions (Cottle *et al.* 2011; Grainger and Beauchemin 2011).

Measuring on-farm GHG emissions is both timely and expensive. Estimations based on internationally recognised methodologies, algorithms and emission factors is viewed as the most effective method of estimating a farms' GHG emissions. However, using such an approach fails to recognise the uncertainty that exist around a single emission factor value. Adopting a stochastic assessment approach assists in quantifying the variability around a farms' GHG emissions by accounting for the uncertainty that exist around certain emission factors. To date, while a literature review has been able to identify stochastic uncertainty assessments for the beef (Foley *et al.* 2011) and dairy production systems (Lovett *et al.* 2008; Basset-Mens *et al.* 2009) no such assessment has been found for lamb production.

The Monte Carlo stochastic uncertainty assessment highlighted the variation that exists around key emission factors and their influence on the GHG emissions of lamb production. The influence of varying all emission factors values, other than for CH_4 emissions from animal waste (due to its minimal contribution to total GHG emissions) was explored. In most instances, the minimum and most likely emission factor values were similar. However, the maximum emission factor value for many of the sources of emissions was quite divergent from the most likely value. The uncertainty associated with the emission factors for calculating direct N_2O emission from urine deposition was shown to have the greatest effect on the uncertainty of emissions intensity for both lamb production enterprises. The minimum and most likely N_2O emission factors for urine deposition were 0.3% and 0.4%, respectively. However, the maximum N_2O emission factor value for urine was 7.5 times greater than the most likely emission factor value. The large variation around emission factors, as reported in the IPCC methodology (2006), highlights the extreme uncertainty that exist when estimating GHG emissions and how difficult it is to provide accurate estimations of GHG emissions under varying environmental conditions and/or livestock scenarios. This identifies the need for further research across a range of environmental and livestock scenarios to better quantify the variation around each emission factor so that a greater level of confidence can be placed in GHG estimations. Research is also required to identify which conditions are conducive to high GHG emissions so that appropriate abatement strategies can be developed and implemented on-farm when these conditions present themselves.

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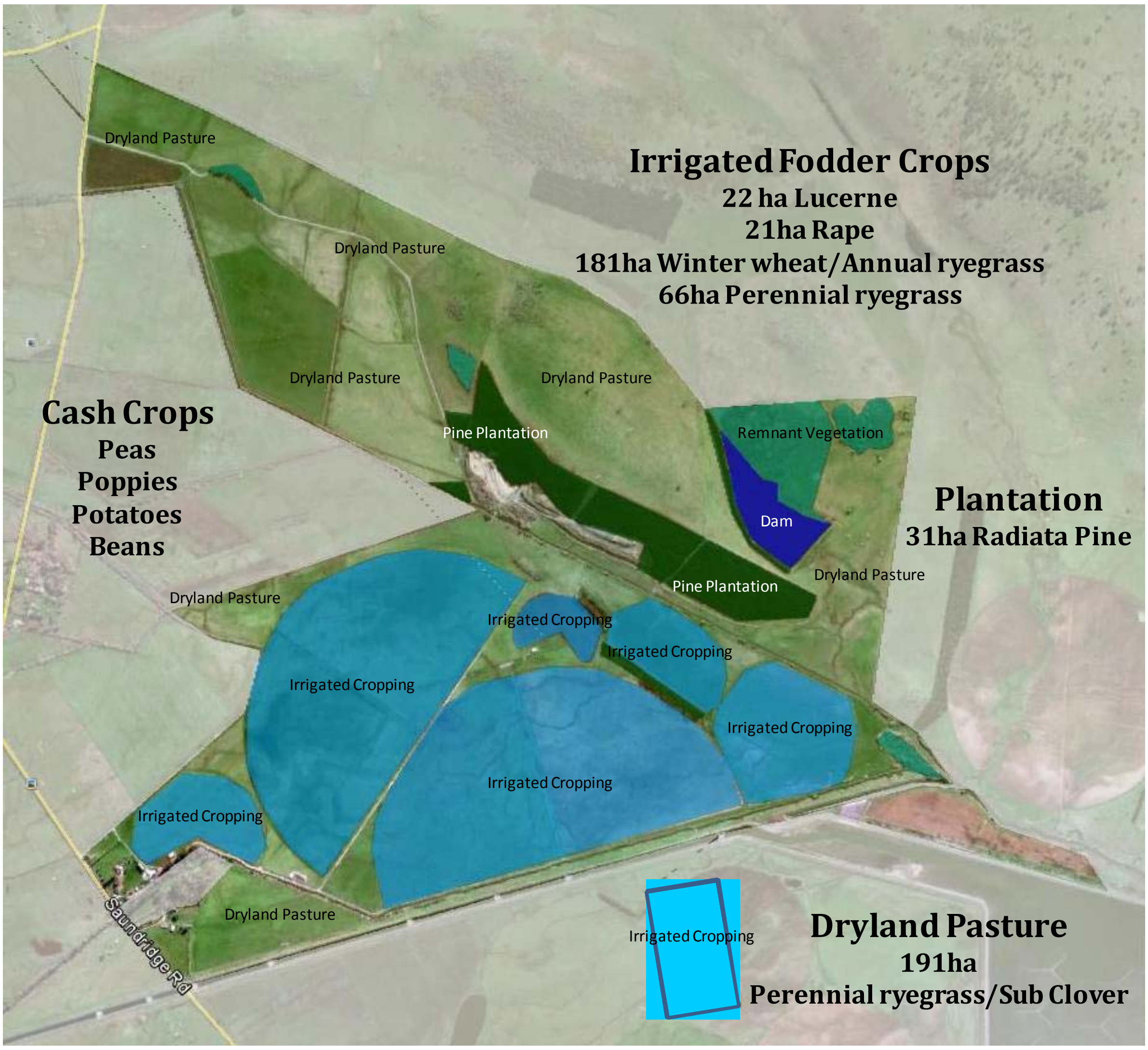
Appendices

Appendix 1 Farm map showing areas of irrigated pastures and crops, areas of dryland pastures, pine plantation and remnant vegetation



Appendix 2 Screenshots of data entry for the two lamb enterprises combined in FarmGas

Enterprise Area: 481.0 hectares
Enterprise Type: XB Prime Lamb

Enter Flock Details

Breeding Ewes	1200	head
Maiden Ewes	285	head
Other (Dry) Ewes	0	head
Lambs/Hoggets	0	head
Rams	35	head
Wethers	0	head
Weaning %	129	%
Mortality %	0.0	%

DSE (Dry Sheep Equivalent) Values

Class	DSE/hd	Total DSEs
Breeding Ewes	2.0	2400
Dry Ewes	1.5	428
Lambs/Hoggets	0.5	0
Rams	2.0	70
Wethers	1.0	0
Total DSE at start:		2898

Lambing - by Season		Spring	Summer	Autumn	Winter
Enter % of Lambing each season		100	0	0	0
Number of lambs weaned per year/season:	1915	1915	0	0	0

Sales and Purchases Details

Sales	Total Numbers available (adjusted for purchases & deaths)	Spring	Summer	Autumn	Winter
Breeding Ewes Culled/CFA	1118	0	0	82	0
Maiden Ewes (1 yo) Culled	285	0	0	0	0
Other Ewes (Dry)	0	0	0	0	0
Lambs/Hoggets	343	0	1114	4879	1049
Rams	19	0	0	16	0
Wethers	0	0	0	0	0

Purchases	Total Purchased	Spring	Summer	Autumn	Winter
Breeding Ewes	0	0	0	0	0
Maiden Ewes	0	0	0	0	0
Lambs/Hoggets	5470	2149	2164	627	530
Rams	0	0	0	0	0
Wethers	0	0	0	0	0

Appendix 3 Screenshots of data entry for the home-bred lamb enterprise in FarmGas (no purchases so not shown)

Enterprise Area: 481 hectares
Enterprise Type XB Prime Lamb

Enter Flock Details

Breeding Ewes	1200	head
Maiden Ewes	285	head
Other (Dry) Ewes	0	head
Lambs/Hoggets	0	head
Rams	35	head
Wethers	0	head
Weaning %	129	%
Mortality %	0.0	%

DSE (Dry Sheep Equivalent) Values

Class	DSE/hd	Total DSEs
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Lambs/Hoggets	0.5	0
Rams	2.0	70
Wethers	1.0	0
Total DSE at start:		2898

Lambing - by Season		Spring	Summer	Autumn	Winter
Enter % of Lambing each season		100	0	0	0
Number of lambs weaned per year/season:	1915	1915	0	0	0

Sales and Purchases Details

Sales	Total Numbers available (adjusted for purchases & deaths)	Spring	Summer	Autumn	Winter
Breeding Ewes Culled/CFA	1118	0	0	82	0
Maiden Ewes (1 yo) Culled	285	0	0	0	0
Other Ewes (Dry)	0	0	0	0	0
Lambs/Hoggets	343	0	145	1143	284
Rams	19	0	0	16	0
Wethers	0	0	0	0	0

Appendix 4 Screenshot of data entry for the home-bred lamb enterprise in the Framework calculator

		Rams	Wethers	Maiden Breeding Ewes	Breeding Ewes	Other Ewes	Lambs and Hoggets		
Livestock Numbers	Winter	35	0	285	1200	0	1183	Is your prope	
	Spring	35	0	285	1200	0	1869	N	Er
	Summer	19	0	285	1118	0	995		
	Autumn	19	0	285	1118	0	345		
	Average	27	0	285	1159	0	1098		
Liveweight	Winter	80	0	70	70	0	10		
(kg per animal)	Spring	80	0	70	70	0	35		
	Summer	80	0	70	70	0	45		
	Autumn	80	0	70	70	0	50		
	Average	80	0	70	70	0	35		
	DSE	1.6	0	1.4	1.4	0	0.7		
Live weight gain	Winter	0	0.00	0	0	0	0.1		
(kg/day)	Spring	0.00	0.00	0.00	0.00	0.00	0.30		
	Summer	0.00	0.00	0.00	0.00	0.00	0.15		
	Autumn	0.00	0.00	0.00	0.00	0.00	0.10		
Dry Matter Availabilit	Winter	1	0	1.2	1	0	1.2		
(tonnes/ha)	Spring	2	0	2	2	0	2		
	Summer	1.2	0	1.2	1.2	0	1.5		
	Autumn	1.8	0	1.8	1.8	0	1.5		
Lambing Rates	Winter				1				
(% of ewes lambing)	Spring				0				
	Summer				0				
	Autumn				0				
Crude Protein	Winter	22	0	22	22	0	24		
(%)	Spring	20	0	20	20	0	24		
	Summer	14	0	14	14	0	24		
	Autumn	14	0	14	14	0	24		
DMD	Winter	75	0	75	75	0	75		
(%)	Spring	75	0	75	75	0	75		
	Summer	60	0	60	60	0	75		
	Autumn	70	0	70	70	0	75		

Appendix 5 Screenshot of data entry for the purchased lamb enterprise in the Framework calculator

Enter your farm data for each animal class and season

		Rams	Wethers	Maiden Breeding Ewes	Breeding Ewes	Other Ewes	Lambs and Hoggets
Livestock Numbers	Dec-Feb	0	0	0	0	0	1789
	Mar-May	0	0	0	0	0	2905
	Jun-Aug	0	0	0	0	0	894
	Sep-Nov	0	0	0	0	0	432
	Average	0	0	0	0	0	1505
Liveweight (kg per animal)	Dec-Feb	0	0	0	0	0	38
	Mar-May	0	0	0	0	0	48
	Jun-Aug	0	0	0	0	0	54
	Sep-Nov	0	0	0	0	0	48
	Average	0	0	0	0	0	47
	DSE	0	0	0	0	0	0.94
Live weight gain (kg/day)	Dec-Feb	0	0.00	0	0	0	0.25
	Mar-May	0.00	0.00	0.00	0.00	0	0.25
	Jun-Aug	0.00	0.00	0.00	0.00	0	0.25
	Sep-Nov	0.00	0.00	0.00	0.00	0	0.25
Dry Matter Availabilit (tonnes/ha)	Dec-Feb	0	0	0	0	0	2
	Mar-May	0	0	0	0	0	1.5
	Jun-Aug	0	0	0	0	0	1.5
	Sep-Nov	0	0	0	0	0	1.2
Lambing Rates (% of ewes lambing)	Dec-Feb				0		
	Mar-May				0		
	Jun-Aug				0		
	Sep-Nov				0		
Crude Protein (%)	Dec-Feb	0	0	0	0	0	24
	Mar-May	0	0	0	0	0	24
	Jun-Aug	0	0	0	0	0	24
	Sep-Nov	0	0	0	0	0	24
DMD (%)	Dec-Feb	0	0	0	0	0	75
	Mar-May	0	0	0	0	0	75
	Jun-Aug	0	0	0	0	0	75
	Sep-Nov	0	0	0	0	0	75