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4 AUTHORS, INCLUDING:

Wahidul K Biswas
Curtin University

Kevin Kelly
Department of Environment and Primary In…

Michele B John
Curtin University

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Global warming contributions from wheat, sheep meat and wool production in Victoria, Australia – a life cycle assessment

Wahidul K. Biswas [a,*], John Graham [b], Kevin Kelly [b], Michele B. John [a]

[a] Centre of Excellence in Cleaner Production, Curtin University of Technology, Western Australia 6845, Australia
[b] Department of Primary Industries, Victoria 3300, Australia

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ABSTRACT

This paper compares the life cycle global warming potential of three of Australia's important agricultural production activities – the production of wheat, meat and wool in grazed subterranean clover (sub-clover) dominant pasture and mixed pasture (perennial ryegrass/phalaris/sub-clover/grass and cape weed) systems. Two major stages are presented in this life cycle assessment (LCA) analysis: pre-farm, and on-farm. The pre-farm stage includes greenhouse gas (GHG) emissions from agricultural machinery, fertilizer, and pesticide production and the emissions from the transportation of these inputs to paddock. The on-farm stage includes GHG emissions due to diesel use in on-farm transport and processing (e.g. seeding, spraying, harvesting, topdressing, sheep shearing), and non-CO_2 (nitrous oxide (N_2O), and methane (CH_4)) emissions from pastures and crop grazing of lambs.

The functional unit of this life cycle analysis is the GHG emissions (carbon dioxide equivalents – CO_2 -e) from 1 kg of wheat, sheep meat and wool produced from sub-clover, wheat and mixed pasture plots. The GHG emissions (e.g. CO_2, N_2O and CH_4 emission) from the production, transportation and use of inputs (e.g. fertilizer, pesticide, farm machinery operation) during pre-farm and on-farm stages are also included. The life cycle GHG emissions of 1 kg of wool is significantly higher than that of wheat and sheep meat. The LCA analysis identified that the on-farm stage contributed the most significant portion of total GHG emissions from the production of wheat, sheep meat and wool. This LCA analysis also identified that CH_4 emissions from enteric methane production and from the decomposition of manure accounted for a significant portion of the total emissions from sub-clover and mixed pasture production, whilst N_2O emissions from the soil have been found to be the major source of GHG emissions from wheat production.

1. Introduction

Whilst the agricultural sector accounts for 3% of GDP and 4% of employment in Australia (Australian Bureau of Statistics, 2008), in 2008 agricultural emissions represented 15.6% of Australia's total net greenhouse emissions in the National Greenhouse Gas Inventory (Department of Climate Change, 2008). These GHG emissions will increase further as Australia's agricultural export production is expected to double over the next 10 years (Biswas and John, 2008). Wheat, sheep meat and wool are major agricultural commodities that have accelerated the growth of Australian exports over many years (Australian Bureau of Statistics, 2008; Sheep Meat Council of Australia, 2009). Understanding the global warming impacts of their production on the environment will be increasingly important in a carbon constrained economy.

The predominant greenhouse gases emitted from agriculture are methane (CH_4) and nitrous oxide (N_2O), which respectively possess 21 and 310 times the global warming potential of carbon dioxide (CO_2) (IPCC, 2006). Nationally, agriculture is the dominant source of both methane (59%) and nitrous oxide (84%) emissions (Department of Climate Change, 2008). Other than emissions from the paddock, pre-farm (e.g. production of fertilizer, pesticide etc.) and on-farm operation (seeding, ploughing, harvesting) emit a significant portion of global warming emissions during the life cycle of agricultural production (Biswas and John, 2008; Biswas et al., 2008a). Whilst these studies assessed the life cycle greenhouse emissions of grains and grain products, no local study has to date determined the life cycle greenhouse emissions from sheep meat and wool production in grazed subterranean clover (sub-clover) dominant pasture and mixed pasture (perennial ryegrass/phalaris/sub-clover/grass and cape weed) systems. Similar studies

* Corresponding author.
E-mail address: w.biswas@curtin.edu.au (W.K. Biswas).

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have assessed the climate change impacts of Australian livestock and wool industries, but have not utilized a life cycle assessment approach (Howden and Reyenga, 1990; McCrabb and Hunter, 1999; Harlea and Howden, 2007).

Life Cycle assessment can assist in determining the overall material and energy efficiency of an agricultural system and can assist in the identification of 'hotspots' or polluting stages in production systems. Additional trade-offs in materials, energy, and GHG emissions will also importantly provide an ability to benchmark and measure the benefits associated with different management approaches and the development of more sustainable future farming systems.

Given the challenges between economic/production output and environmental impact assessment, a holistic approach is therefore needed if the overall impact of agricultural production systems on global greenhouse gas (GHG) emissions is to be addressed. A 'life cycle assessment' (LCA) can be undertaken to account for all the GHG's emitted from all stages of agricultural production so that mitigation strategies can focus on the primary sources of the GHG emissions (Narayanaswamy et al., 2005). An LCA compiles the inputs and outputs of a production system, and in turn evaluates their potential environmental impacts (e.g., GHG emissions) (Ekvall and Finnveden, 2001). This has the advantage of identifying the environmental impacts of all stages in the production cycle, rather than focusing on a single source of GHG emission (e.g., N_2O emission from the application of N fertilizer) (Greadel and Allenby, 2003a). Secondly, LCA enables evaluation of environmental impacts such as the global warming potential for comparative or improvement purposes (Greadel and Allenby, 2003b). Thirdly, this LCA analysis assists in the identification of the 'hotspots' or stages causing the most GHG emissions.

The studies which have been conducted to date have considered the use of LCA for assessing the environmental impact of crops or crop based products and beef (Braschkat et al., 2003; Beer and Grant, 2005; Casey and Holden, 2006; Gasol et al., 2007; Peters et al., 2010), however, there has been no comparative study to date on the comparative life cycle environmental impacts associated with three of Australia's most important agricultural production activities – wheat, sheep meat and wool production. A comparative study can identify which of these three products would require immediate pollution mitigation strategies and identify the process causing the most pollution.

The LCA research highlighted in this paper has identified only the global warming impact or the greenhouse gas (GHG) emissions associated with wheat, sheep meat and wool production from sub-clover, mixed pasture and wheat production systems. This also enables assessment of the GHG emission changes when converting from long term pastures into a cropping system, which is occurring at an increasing rate in the high rainfall zone (HRZ) of south west Victoria. One of the systems used in this conversion is a legume crop rotation system where N fertilizer is replaced by the N fixation property of the legume. Finally, the life cycle assessment could enable livestock and grain industries to further market the sustainability benefits in a competitive and carbon constrained market by undertaking GHG mitigation strategies.

This LCA study resulted from a research project which investigated how farm management systems can influence nitrous oxide gas emissions in the high rainfall cropping regions of south west Victoria (Department of Primary Industries, 2007).

2. Methodology

The LCA approach used in this paper assessed GHG emissions from pre-farm (e.g., manufacturing of farming inputs, e.g. fertilizer, machinery etc), and on-farm (e.g., application of fertilizer, farm machinery operation etc) stages of wheat, meat and wool production on sub-clover, wheat and mixed pasture (perennial ryegrass/phalaris/subterranean clover/grass and cape weed) plots with each plot about 5 m × 15 m at the study site in Hamilton, Victoria.

Only sub-clover was grown in the sub-clover plot. In the wheat plot, there was only wheat stubble and some perennial weeds for grazing after wheat harvest. The sub-clover was used in conjunction with the wheat in a sub-clover/wheat rotation system, to utilize the soil nitrogen produced by the sub-clover, in lieu of using N fertilizer. In this pasture/sub-clover crop rotation system, the clover pasture is established by spraying out the grasses to produce a clover dominant pasture prior to direct drilling with wheat. After the clover year phase, clover is sprayed out in the autumn, and wheat is direct drilled, the wheat crop benefiting by the nitrogen fixation of the clover, then after the year of wheat, the clover germinates and becomes a clover sward used to graze sheep to continue the rotation system. The mixed pasture comprised of perennial grass weeds (16%), cape weed (17%), clover (25%), perennial ryegrass and phalaris (39%) and others (3%).

Using the LCA approach, GHG emissions from manufacturing of inputs for wheat, sheep meat and wool production (chemicals, energy and machinery), transportation, machinery operation, animals and paddock have been calculated. The LCA followed the ISO14040-43 guidelines ISO, (1997) and is divided into four steps: 1) goal and scope definition; 2) inventory analysis; 3) impact assessment; and 4) interpretation (as presented in the 'Results' section of this paper).

The information for this LCA analysis was based on the experimental results at DPI Hamilton, Victoria (DPIV) (37°49′S, 142°04′E, altitude, 205 m), on a basalt derived duplex soil (Cayley et al., 2002). During the year of continuous nitrous oxide emission measurements, rainfall at the site was 727 mm compared with the long term average of 685 mm per annum. Nitrous oxide emissions were measured on the 3 different systems using automated chambers connected to a gas analyzer.

2.1. Goal and scope

The goal was to compare the life cycle global warming performance of wheat, sheep meat and wool, produced in three adjacent plots: mixed pasture, wheat and sub-clover. This was achieved by establishing the functional unit, selecting the relevant system boundaries and determining data requirements. The functional units were based on the '*cradle to farm-gate*' perspective, where wheat, meat (sold as live lambs) and greasy wool from three plots are end products sold off the farm. The GHG emissions derived from producing 1 kg of wheat, sheep meat and wool from mixed pasture, wheat and sub-clover over a one year period were considered as functional units for this LCA analysis.

The LCA was divided into two main stages; pre-farm and on-farm. Pre-farm data includes information on the production of inputs, such as fertilizer, pesticides and herbicide, also the combustion of diesel in transporting the inputs to the farm. On-farm activities were based on a 12-month field study conducted at the Department of Primary Industries site in Hamilton, Victoria (March 2007–February 2008). Additional farm machinery operation, i.e. sheep shearing, was considered for greasy wool production only. The greasy wool is the wool in its natural state as sold off the farm, which is obtained after removal from the sheep and before any commercial processing. At this stage it contains yolk, suint[1], moisture, extraneous soil and vegetable matter. GHG emissions

[1] A natural grease formed from dried perspiration found in the fleece of sheep, used as a source of potash.

relating to the conversion of greasy wool to clean wool were not considered. The meat processing activities are done off farm, so no GHG emissions from meat processing were considered. As sheep meat is considered sold at the farm gate, GHG emissions relating to the transportation of sheep to slaughterhouse/saleyard were also not included.

Annual average number of sheep grazed on the clover and mixed pasture plots was 15, while only 4 sheep grazed on the wheat plot during the fallow period. The wheat plot was grazed from March 07 until 10 days before spraying and sowing on 30 May 07. Crop residue were grazed by sheep from 15 January 08 for about 5–6 weeks post harvest.

A land preparation stage was not included in the analysis, as minimum tillage is common practice in the area, and this conservation tillage (direct drilling) was used to sow the wheat. Following Biswas et al. (2008a), carbon dioxide uptake from crop growth was not considered as much of the plant material was retained on site following harvest. Therefore, it was assumed that the sequestered CO_2 would be re-released with time. Soil carbon sequestration was also not included in this analysis as it was not considered to be significant during a 12-month period (Department of Primary Industries, 2008).

As some of the databases for certain chemicals (e.g. some herbicides and pesticides), were not available, surrogate values have been used. For example, "Clethodim", which is used as an herbicide, has been replaced by an equivalent amount of "Glyphosate" for this LCA analysis. The database for one particular pesticide, known as "Propiconazole", was unavailable, and the Australian emission data for a generic pesticide was used as a surrogate (Royal Melbourne Institute of Technology, 2007).

The mustering of sheep for crutching, drenching and marking, vaccination and weaning etc and general animal management have been excluded from the analysis, as it was considered that reasonably low amount of fuel would be used particularly if the mustering was done by 4 wheel bike.

2.2. Life cycle inventory

The life cycle inventory (LCI) considers the amount of each input and output (or emissions) for processes which are required to produce each end product (farm gate). Undertaking an LCI is a necessary initial step in order to carry out an LCA analysis. Table 1 shows the annual inputs and outputs of the pre-farm and on-farm stages to produce wheat, sheep meat and wool from sub-clover, wheat and mixed pasture plots in a hectare of land in three adjacent plots.

As can be seen in Table 1, 525 kg of meat and 75 kg of wool can be produced from 15 sheep grazed in both sub-clover and mixed pasture plots and 6.2 ton of wheat and 20 kg of wool from sheep grazed in the wheat plot. The information on the average amount of sheep meat and wool per lamb was obtained from MLA (Meat and Livestock Australia, 2007) and DPI Hamilton. The meat production from the wheat plot was not considered, because grazing the sheep on the stubble in the autumn period is most likely to just maintain the live weight of sheep – with the sheep having already been weaned.

Since multiple products are produced from each of the three plots, the environmental burden associated with production (i.e. GHG emissions) needs to be allocated for each of the products. The CO_2 environmental burden can either be allocated by physical value of the inputs used, for co-products production or from the economic values of co-products. Since the physical values of inputs cannot be differentiated for co-products, an economic allocation method was used to calculate the inputs and outputs of co-products (Guinee and Heijungs, 2004). In this method the allocation factors to partition the greenhouse emissions to the various products (wool, sheep meat and wheat) are derived using the ratio of market value for those products (see Table 2). Market values of wheat, sheep meat and wool were obtained from Meat and Livestock Australia (2007), the Australian Wheat Board (Desborough, 2009) and DPI, Victoria (Department of Primary Industries, 2008). Table 2 shows the allocation factors for meat, wheat and wool produced in sub-clover, wheat and mixed pasture plots. Using the allocation factors and input and output values in Table 1, input and output values of 1 kg of wheat, meat and wool produced from three plots were then calculated.

Table 1
Life cycle inventory of wheat, sheep meat and wool production in sub-clover, wheat and mixed pasture plots on an annual basis. (The pre- and on-farm figures included refer to the GHG conversion factors used for each item in the LCA database).

	Unit	Sub-clover	Wheat	Mixed pasture
Pre-farm				
Super phosphate	kg/Ha	360	590	360
Glyphosate	kg/Ha	1.2	0.54	
Pesticide	kg/Ha		0.13	
Farm machinery	USD/Ha	8.7E-03	1.9E-01	4.9E-03
Transport of chemicals	tkm	65.90	106.05	64.53
Transport of farm machinery	tkm	134.80	478.24	130.76
On-farm				
Farm machinery operations				
Seeder	litres/Ha		1.82	
Sprayer	litres/Ha	0.65	1.96	
Top dresser	litres/Ha	0.81	0.81	0.81
Harvester	litres/Ha		0.91	
Sheep shearing	kWh/Ha	0.62	0.16	0.62
Emissions from paddock				
CH_4 emissions from excreta	kg/Ha	2.7E-02	7.7E-03	2.7E-02
CH_4 emissions from belching	kg/Ha	164.25	46.43	164.25
N_2O emissions	kg/Ha	2.20	5.03	1.10
Final products				
Meat	kg/Ha	525		525
Wool	kg/Ha	75	20	75
Wheat	kg/Ha		6.2	

2.3. Impact assessment

The environmental impact assessment of wheat, sheep meat and wool production for pre-farm, and on-farm activities included two steps. The first step calculates the total gases produced in each process and the second step converts these gases to CO_2 equivalent.

Table 2
Product, market value and allocation factors of inputs for the production of wheat, sheep meat and wool.

	Sub-clover plot	Wheat plot	Mixed pasture plot
Multi-product flow (kg/Ha/year)			
Wheat		6.2	
Sheep meat	525		525
Wool	75	20	75
Market value (AUD)			
Wheat		1953	
Sheep meat	900		900
Wool	390	104	390
Total	1290	2057	1290
Allocation factors			
Wheat		0.95	
Sheep meat	0.7		0.7
Wool	0.3	0.05	0.3

Stage 1: The input and output data in the LCI were inserted into *Simapro 7* (PRé Consultants, 2008) software to calculate the GHG emissions associated with the production of 1 kg of wheat, sheep meat and wool from sub-clover, wheat and mixed pasture plots. The input/output data of the LCI were linked to relevant libraries in *Simapro 7.* The library is a database that consists of energy consumption, emission and materials data for the production of one unit of a product. The units of input and output data of the LCI depend on the units of the relevant materials (i.e. kg, l, MJ, $ etc.) in *Simapro* or associated libraries.

– Libraries for chemicals: The Australian LCA database (Royal Melbourne Institute of Technology, 2007) was used to calculate GHG emissions from the production of chemical inputs, such as pesticides, and herbicide. The emission factor for single super phosphate was obtained from the fertilizer manufacturer (CSBP Ltd, Perth; C. Schuster pers. comm.) as the data was unavailable from the Australian database. The supply chain for the fertilizers, herbicides and pesticides, including production and transportation to the point of use (or paddock), was incorporated in order to assess the GHG emissions during the pre-farm stage. Data obtained from DPI for the Hamilton site shows that a 30 tonne articulated truck, which is widely used in the rural Australia, travelled 234 km to carry single super phosphate, 284 km to carry herbicide, between 1159 km and 1180 km to carry pesticide and 11,047 km to carry machinery to the paddock. The unit for transport is tonne-kilometre (tkm). For example, 0.234 tkm is required to carry 1 kg of herbicide for 234 km (i.e. 0.001 ton $\times$ 234 km). GHG emissions from transportation were equivalent to 0.076, 86 $\times$ 10^{-4} and 13 $\times$ 10^{-4} kg/tkm of CO_2, CH_4 and N_2O, respectively (Royal Melbourne Institute of Technology, 2007).
– Farm machinery library: The USA input-output database for 1998 was used to assess the GHG emitted from manufacturing farm machinery (PRé Consultants, 2008). This database contains environmental emission data for the production of US $ 1 equivalent farm machinery in 1998. The current price of farm machinery was deflated to a 1998 price (in AUD) at 3% per year. Following this, the 1998 price of machinery in AUD/hectare has been converted into 1998 US dollars (by multiplying by 0.6).
– Farm machinery operation library: The farm machinery, which consumes less than 500 MJ ha^{-1}, is regarded as light duty machinery (Nemecek et al., 2004). Therefore, the library for light duty agricultural machinery was used to calculate the potential GHG emitted from farm machinery operation. The emission factors were obtained from RMIT's LCA database (Royal Melbourne Institute of Technology, 2007).
– Paddock emissions: Methane emissions during grazing came from enteric CH_4 and manure decomposition. Because of the absence of local data from actual GHG emission data from animal grazing, CH_4 emissions from manure have been calculated using the methodology for the estimation of greenhouse gas emissions and sinks, developed by the National Greenhouse Gas Inventory Committee (Department of Climate Change, 2006). The formula used to calculate the CH_4 emission is as follows:

  – Manure methane = Intake $\times$ (1 − dry matter (DM) digestibility) $\times$ methane emission factor (Methane Emission Factor for temperate regions 1.4 $\times$ 10^{-5}).
  – The daily emission from manure from 1 sheep grazing 1.19 kg DM/day with a dry matter digestibility of 70%, would be 1.19 $\times$ 0.30 $\times$ 1.4 $\times$ 10^{-5} = 0.000005 kg CH_4/head/day or 0.00182 kg CH_4/head/year.
  – If we were to take this at 15 sheep/ha, the output would be 0.027 kg CH_4/ha/year. If enteric methane loss or CH_4 emissions from belching was 30 g/head/day or 10.95 kg CH_4/head/year, then the total emissions for 15 lambs will be 164 kg CH_4/ha/year.

Table 3
GHG emissions (kg CO_2-eq) in two stages of the life cycle of one kg of wheat, sheep meat and wool production.

	Sub-clover		Wheat		Mixed pasture	
	Sheep meat	Wool	Wheat	Wool	Sheep meat	Wool
Pre-farm						
Super phosphate	1.8E-02 (0.3%)	1.8E-02 (0.3%)	3.4E-03 (0.9%)	0.9E-02 (0.3%)	1.8E-02 (0.4%)	1.8E-02 (0.4%)
Glyphosate	1.4E-02 (0.3%)	1.4E-02 (0.3%)	7.4E-04 (0.2%)	1.2E-02 (0.2%)		
Pesticide			2.7E-04 (0.1%)	4.5E-03 (0.1%)		
Farm machinery	1.1E-05 (0.01%<)	3.2E-05 (0.01%<)	2.7E-05 (0.01%<)	4.3E-04 (0.01%<)	6.0E-06 (0.01%<)	1.8E-05 (0.01%<)
Transport	9.4E-03 (0.2%)	2.8E-02 (0.2%)	5.8E-03 (1.4%)	9.5E-02 (1.4%)	9.0E-03 (0.2%)	2.7E-02 (0.2%)
Sub-total	4.2E-02 (0.8%)	1.3E-01 (0.8%)	1.0E-02 (2.6%)	1.7E-01 (2.6%)	2.7E-02 (0.6%)	8.2E-02
On-farm						
Farm machinery operations	1.2E-02 (0.2%)	3.7E-02 (0.2%)	4.4E-03 (1.1%)	7.2E-02 (1.1%)	6.6E-03 (0.1%)	2.0E-02 (0.1%)
CH_4 emissions from excreta	7.6E-04 (0.01%)	2.3E-03 (0.01%)	8.3E-05 (0.02%)	1.4E-03 (0.02%)	7.6E-04 (0.02%)	7.6E-03 (0.02%)
CH_4 emissions from belching	4.60 (82.7%)	13.80 (82.7%)	0.15 (37.1%)	2.44 (37.1%)	4.60 (90.4%)	13.80 (90.4%)
N_2O emissions	0.91 (16.3%)	2.73 (16.3%)	0.24 (59.3%)	3.90 (59.3%)	0.45 (8.9%)	1.36 (8.9%)
Sub-total	5.52 (99.2%)	16.56 (99.2%)	0.39 (97.4%)	6.41 (97.4%)	5.06 (99.4%)	15.18 (99.4%)
Total life cycle GHG emissions	5.56 (100%)	16.69 (100%)	0.40 (100%)	6.58) (100%	5.09 (100%)	15.26 (100%)

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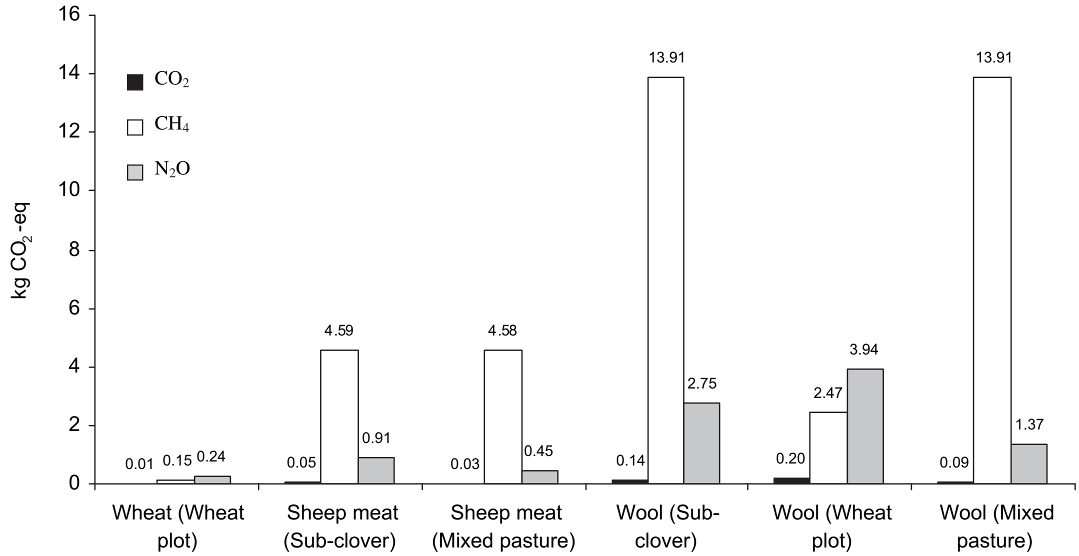

Fig. 1. CO_2-eq emissions of three greenhouse gases for 1 kg wheat, sheep meat and wool production.

– Total soil N_2O-N emissions measured during the on-farm stage were 1.4 kg ha^{-1} yr^{-1}, 3.2 kg ha^{-1} yr^{-1} and 0.7 kg ha^{-1} yr^{-1} for sub-clover, wheat and mixed pasture plots, respectively.

Stage 2: Once the inputs/outputs are linked to the relevant libraries, *Simapro* software calculated the GHG emissions by converting each selected GHG to CO_2 equivalents (Biswas et al., 2008a). The program sorted GHG from the selected libraries, and then converted each selected GHG to CO_2 equivalents (or kg CO_2-eq). Nitrous oxide and CH_4 are 310 and 21 times more powerful than CO_2, respectively (Australian Bureau of Statistics, 2008). Finally, all CO_2 equivalent GHG emissions for all life cycle inventory items are added to determine the full life cycle GHG emissions associated with production.

3. Results and discussions

3.1. Greenhouse emissions from wheat, sheep meat and wool

Table 3 shows the GHG emissions from the production of 1 kg of wheat, sheep meat and wool produced in three adjacent plots: sub-clover, wheat and mixed pasture. The equivalent of 5.56 and 5.09 kg of CO_2 per year were emitted due to the production of meat from sub-clover and mixed pasture plots, respectively. Other similar studies estimated that around 11 kg CO_2-eq of GHG emissions were emitted per year due to the production of 1 kg of beef, where additional processes like silage production, spreading and storage were included in the LCA analysis (Casey and Holden, 2006; Peters et al., 2010).

The CO_2-eq from the production of sheep meat from the sub-clover plot is higher than that from the mixed pasture, because the pure sub-clover pasture was established for a sub-clover/wheat rotation system predominately to increase the nitrogen content of the soil for the benefit of the crop, therefore, increasing the N_2O emissions.

Similarly, GHG emissions from wool production from the sub-clover plot (i.e. 16.7 kg CO_2-eq) are higher than that from the wool production in the mixed pasture plot (15.3 kg CO_2-eq). The GHG emissions from the wheat plot are significantly lower than sub-clover and mixed pasture plots, because sheep grazed for only 4 months and therefore the total GHG emissions from belching and excreta were less than those emitted from the annually grazed sub-clover and mixed pasture plots. The GHG emissions from wheat production (0.4 kg CO_2-eq/kg) was significantly lower than that from sheep meat and wool production when compared on a kilogram basis, however when compared on a per hectare basis, whilst still lower, the wheat at 2480 CO_2-eq/kg was nearer the emissions of sheep meat from mixed pasture (2672 CO_2-eq/kg) and sub-clover (2940 CO_2-eq/kg).

As can be seen in Table 3, the on-farm stage contributed significantly higher GHG emissions than the pre-farm stage during the life cycle of each of these products. GHG emissions from pre-farm and on-farm stages of sheep meat and wool production from the mixed pasture plot accounted for 0.8% and 99.2% of total GHG emissions, 2.6% and 97.4% for grains and wool production from the wheat plot and 0.5% and 99.5% for meat and wool production from mixed pasture plots. CH_4 emissions from the belching and decomposition of animal excreta during the on-farm stage accounted for a significant proportion (83–90%) of the total GHG emissions from mixed pasture and sub-clover plots. In the case of the wheat plot, N_2O emissions from soil emissions accounted for a significant portion (59%) of the total GHG emissions.

3.2. CO_2-eq emissions from three greenhouse gases

Fig. 1 shows the total annual emissions of three GHGs, including CO_2, CH_4 and N_2O, emitted from the production of 1 kg of wheat, meat and wool produced on three adjacent sub-clover, wheat and mixed pasture plots. The emissions of CH_4, followed by N_2O and CO_2, respectively, have been found to be the major greenhouse gases emissions from mixed pasture and sub-clover plots, whilst N_2O is the major greenhouse gas, emitted from the wheat plot.

Table 4
Impact of price fluctuation on the carbon foot prints or carbon emissions (kg CO_2-eq) of wheat, sheep meat and wool.

		Sub-clover		Wheat		Mixed pasture	
		Meat	Wool	Grains	Wool	Meat	Wool
Base case		5.5	16.8	0.4	6.6	5.1	15.4
Wool price	20% rise	5.2	19.0	0.4	7.9	4.8	17.4
	20% fall	5.9	14.3	0.4	5.4	5.4	13.1
Sheep meat price	15% rise	5.8	15.2	0.4	6.6	5.3	13.9
	15% fall	5.3	18.8	0.4	6.6	4.8	17.2

Table 5
Comparison of LCAs for one kg of wheat in Hamilton, Victoria and Cunderdin, WA.

LCAs	kg CO_2-eq Global Warming potential		
	Pre-farm	On-farm	Total
Wheat plot, Hamilton, Vic (Current study)			
With methane	0.1	0.39	0.4
Excluding methane emissions from sheep	0.1	0.24	0.25
Wheat plot, Cunderdin WA (Biswas et al., 2008a)	0.13	0.14	0.27

Unlike previous studies (Biswas et al., 2008a,b), CO_2 emissions do not account for a significant proportion of the total emissions in these production scenarios.

The data indicates that to reduce per hectare emissions from this wheat production system, emphasis should be concentrated on reducing N_2O emissions, whereas with the mixed pasture and sub-clover emphasis should be given to the reduction of methane emissions from the sheep digestion. The sub-clover plots produced more emissions than the mixed pasture system. In the mixed pasture, there are grasses with clover, and therefore the uptake of N in this plot is higher than the sub-clover plot. Since the uptake of N is higher in the mixed pasture plot than that in the sub-clover plot, the loss of N or the overall GHG emissions from the mixture plot is less than the sub-clover plot.

3.3. Impact of price fluctuation on the greenhouse gas emissions

Since the allocation of carbon foot prints in these mixed farming systems are allocated on the market values of grains, sheep meat and wool, the fluctuation of these commodity prices may change the carbon foot prints. The fluctuation of the price of grain was not significant (5%) compared to sheep meat (15%) and wool (20%) (ABARE, 2009a,b). Therefore, a sensitivity analysis has been carried out to investigate how the GHG emissions of grains, sheep meat and wool vary due to the fluctuation of prices of sheep meat and wool. As can be seen in Table 4, the carbon foot print of sheep meat production can vary between $\pm$3.5% due to the fluctuation in both sheep meat and wool prices, while the GHG emissions of wool can vary between $\pm$14%. Therefore, it appears that the fluctuation of sheep meat and wool prices is very sensitive to the GHG emissions associated with wool production.

3.4. Comparison of LCAs for 1 ton of wheat in Victoria and Western Australia

Life cycle GHG emissions from grain production can vary in different regions due to differences in crop type, climatic conditions, soil type and the production system (Barton et al., 2008). As a result, the life cycle global warming potential of one kg of wheat produced at Cunderdin in Western Australia (Biswas et al., 2008a) and the pre-farm and on-farm stages of wheat production have been compared to that of the current study at Hamilton, Victoria (see Table 5). The total GHG emissions for Hamilton (0.4 kg CO_2 equivalent/kg) wheat production are higher than those associated with wheat production in Cunderdin, Western Australian (0.27 kg CO_2-eq). This difference would be even greater if the additional N_2O produced by the sub-clover was attributed to the wheat. As can be seen in Table 5, emissions per kg of grain from the pre-farm stage of wheat production in Hamilton, Victoria is significantly lower than the emissions from the same stage of wheat production in Cunderdin. This is because the yield of wheat in Hamilton is 2.3 times higher than that in Cunderdin (6.2 v.s 2.7 ton), and the amount of inputs required to grow 1 kg of wheat in Hamilton is less than that required to grow 1 kg of wheat in Cunderdin. In addition, the production of urea fertilizer that was applied in Cunderdin contributed 0.1 kg CO_2-eq, while no urea was applied in the wheat plot in Hamilton, as the nitrogen fixation of the sub-clover has been used for this purpose. CO_2 equivalent emissions from the on-farm stage of wheat production in Hamilton, are significantly higher (187%) than the emissions from the same stage of wheat production in Cunderdin. for two reasons. Firstly, N_2O-N emissions per hectare per year measured from the wheat plot in Hamilton (3.2 kg per hectare) are higher than those emitted from the paddock in Cunderdin (0.11 kg per hectare). Secondly, the wheat plot in Hamilton is grazed briefly pre sowing, and after harvest, resulting in the emissions of methane from the sheep. If the methane emissions associated with grazing sheep in the no-crop period of the year are excluded, the emission from one kg of wheat production at both sites would be similar.

3.5. Mitigation strategies

The Life Cycle Assessment provides an opportunity to identify environmental 'hotspots' in the life cycle of wheat, sheep meat and wool production. These hotspots require the introduction of cleaner production strategies to improve production efficiency and reduce the environmental impact. As can be seen in Table 3, the methane emissions from sheep emerge as the 'hotspots' for the meat and wool life cycle. This methane in the rumen (called enteric methane) is formed during digestion of feed by a range of microbes known as methanogens, utilizing CO_2 and H_2. Enteric methane emissions can be reduced by improving forage quality, improving feed efficiency, and in dairy cattle has been reduced by using condensed tannins in the diet, using more rumen resistant starch, adding fats and oil (Harper and Denmead, 1999; Beauchemin et al., 2007).

Other strategies are also being examined. CSIRO found that the vaccination of sheep was a possibility for reducing methane, however its actions were restricted to only one species of methanogen restricting its use (Baker, 2000). Research in New Zealand is continuing to examine the use of vaccination. New Zealand researchers and others are also examining the use of acetogen bacteria, which are generally found in anaerobic habitat to divert hydrogen away from methane making microbes (Fonty et al., 2007). Unlike methanogens, acetogen bacteria convert CO_2 and H_2 to acetate (CH_3COOH) rather than to methane. The introduction of chemical agents, e.g. nisin, which is a common food preservative, has also been reported to reduce methane emission by 36% in ruminants (Davidson, 2000).

New research in Australia is currently researching the variability of methane outputs across 20 different sheep genetic lines (Hegarty, 2009). Whilst these studies may well show genetics has a role, it is also recognized that nutrition is the primary controller of methane production, so feed conversion efficiency will continue to be a key target in research.

Other approaches to methane reduction include selective breeding of animals that, for unknown reasons, naturally produce less methane, or the use of other feed additives such as ionophores i.e. monensin to reduce methane production.

4. Conclusions and recommendations

GHG emissions from wool production from both sub-clover and mixed pasture plots has been found to have the largest GHG emissions (i.e 16.7 kg CO_2-eq per kg), which is about 3 times higher than the GHG emissions of the sheep meat production from these plots. The emission of CH_4 accounted for a significant portion of GHG emissions from sheep meat and wool production in mixed pasture and sub-clover plots, whilst N_2O is the major greenhouse gas emitted from wheat and wool production from the wheat plot. CO_2 accounted for an insignificant portion of the total emissions during the life cycle of these three products when compared with N_2O and CH_4. The on-farm stage accounted for a significant portion of total GHG emissions from wheat, sheep meat and wool production in sub-clover wheat and mixed pasture plots.

The enteric methane from sheep during the on-farm stage emerges as the hotspot for the meat and wool life cycle, which could be reduced by modifying diets, or in the future the genetic selection of animals that produce less methane.

This study also found that GHG emissions from wheat production (when the sheep methane emissions are included) are 187% higher for the case study in Hamilton, Victoria than in Cunderdin, Western Australia, due to the significantly higher N_2O-N emissions (and rainfall) in Hamilton and grazing activities. In addition, the research highlights the significantly higher GHG impact of sheep and pasture enterprises relative to wheat production in Australia, albeit in comparing results across two different agricultural regions. The research also raises the question of the complexity of accounting for individual systems in a mixed enterprise farming system. However, GHG emissions per kg of grain from the pre-farm stage of wheat production in Hamilton, Victoria is significantly lower than the emissions from the same stage of wheat production in Cunderdin, because nitrogen fixation of the sub-clover was applied in the wheat plot in Hamilton in order to avoid the use of urea.

This LCA analysis suggests an important role for research in both understanding the 'hotspots' created in our agricultural production and helping to guide breeding programs in the development of new pasture, grain and sheep varieties adapted to both climate change and the increasing environmental pressures associated with reduction of greenhouse emissions.

The measurement of nitrous oxide emissions from land use change (conversion of long term pasture to cropping) in the HRZ (High Rainfall Zone) of south west Victoria as reported in this study is quite high (Graham et al., 2009) and the total emissions as estimated by the LCA reported here indicate that this land use change could be problematic for this area. To examine potential mitigation and management strategies, a subsequent study is currently under way to examine the use of nitrification inhibitors to control these nitrous oxide emissions (Department of Primary Industries, Victoria, Sally Officer, pers. comm.). Other options concerning methane emissions have previously been discussed in this paper.

There is an obvious need for additional research in this area, particularly to enable the partitioning of the causes and sources of agricultural emissions.

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