Life cycle global warming potential of wheat production in Western Australia

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Summary

This paper presents a life cycle assessment of one tonne of wheat production in south-western Australia for three major stages: pre-farm, on farm and post farm. The pre-farm stage includes greenhouse gas (GHG) emissions from agricultural machinery, fertiliser, limestone and pesticide production. The on-farm stage includes GHG emissions due to diesel use in on-farm transport (seeding, spraying, swathing, lime application, topdressing, transport to receival bin, etc), lime neutralisation, nitrous oxide (N_2O) emissions from N-fertiliser application and soil disturbance. The post-farm stage includes sources such as grain storage and transportation from receival bin to the nearest port. The equivalent of 171 kg of CO_2 was produced during the production and delivery of one tonne of wheat port. The pre-farm stage, which includes environmental impact of the production of inputs, such as mining, processing, and transportation to the point of use, accounts for the significant portion (58%) of the total global warming potential, followed by on-farm (24%) and post-farm (18%) stages. The production of fertiliser accounts for a significant portion of the impact for pre-farm and on-farm activities for wheat production, while GHG emissions from transportation was predominant during the post-farm stage.

Key words: Global warming, life cycle assessment, wheat production

Introduction

Nitrous oxide (N_2O) emissions from agricultural soils are a concern as they contribute to global warming and the destruction of the ozone layer. Although N_2O is only present as a trace gas in the earth's atmosphere, it has 310 times the global warming potential of carbon dioxide (CO_2) and has a lifespan of ~120 years (Crutzen, 1981). The atmospheric concentration of N_2O in the atmosphere has increased from 275 to 314 ppb since the industrial revolution (Dentener *et al.*, 2001, Houghton *et al.*, 2001). Nitrous oxide emissions from agricultural soils are considered to account for 70–81% of the increase, which has been linked to a global increase in N fertiliser use (Bouwman 1990).

The Australian Grains Industry is seeking to maintain a clean, green industry to the guarantee its long-term productivity, and to ensure access to premium markets by giving attention to its Environmental Supply Chain Management (ESCM). One of the supporting instruments of ESCM is Life Cycle Assessment (LCA); which for grain production, involves the environmental assessment of inputs (e.g., fertiliser, pesticides) and outputs (e.g., CO_2, CH_4 and N_2O) during pre-farm, on-farm and post-farm activities. Previous LCA studies (Narayanaswamy *et al*. 2005) for the Australian Grains Industry, suggested N_2O emissions from land applications of N fertiliser represented more than 50% of greenhouse gas (GHG) emissions from grain production. In order to estimate GHG emissions, these studies have utilised N_2O emission factors (i.e., proportion of N fertiliser emitted as N_2O) derived from

USA data (Narayanaswamy *et al*. 2005). However, extrapolating emission factors from overseas studies to the south-western Australian grain-belt is not appropriate due to differences in N fertiliser management (type, rate and application method), soils and climates; factors demonstrated to influence annual agricultural N_2O emissions (Stehfest & Bouwman, 2006).

The overall aim of this paper is to present the life cycle global warming potential of one tonne of wheat produced in south-western Australia. Our approach is different from the previous LCAs of grain production in Western Australia. Firstly, the present research had investigated 'paddock to port' life cycle of wheat production by identifying the main processes contributing to GHG from pre-farming, on-farm and post-farming stages. Secondly, our LCA approach had incorporated emission factors for N fertiliser that have been derived from a field-based study in south-western Australian.

Materials and methods

Life cycle assessment involves the compilation and evaluation of the inputs (e.g., fertiliser, pesticides) and outputs (e.g., CO_2, CH_4 and N_2O, and then determines the potential environmental impacts of the production system under investigation. The LCA approach used in this paper assesses GHG emission for pre-farming (e.g., manufacture of farming equipment), on-farm (e.g., planting the crop) and post-farming stages (e.g., delivery of grain to port) separately for wheat production in south-western Australia. Using this approach enabled the LCA to assess the GHG emissions of fertiliser, transportation, storage, and combustion of diesel separately. The life cycle assessment consists of four steps as discussed below.

<u>Goal and scope:</u> The goal was to assess CO_2 equivalence impact of wheat transported to port. The life cycle included all processes from 'paddock to port'. This was achieved by establishing the functional unit, selecting the relevant system boundaries, determining data requirements and choosing environmental indicators. The functional unit was one tonne of wheat transported to port for interstate or international trading. Since no information is available on the proportion of wheat transported to different states and countries, the boundary to the LCA was the port.

In the case of on-farm activities, the input and output data for one tonne of wheat production was based on a field study conducted at the Cunderdin Agricultural College in south-western Australia. During the study period (May 2005 to May 2006) 2.7 t ha^{-1} of wheat harvested from plots that received 100 kg N ha^{-1} yr^{-1} as an inorganic fertiliser. Thus, this LCA approach assessed the GHG emissions of the harvesting of one tonne of wheat from 0.4 hectares of land for the treatment condition.

On-farm stage consisted of two steps: sowing to harvesting and harvest to the local bin. Since no-tillage was employed for sowing, the land preparation stage has not been considered in the present LCA analysis. The sowing to harvesting was divided into three periods: first six weeks after sowing; from six weeks to just before harvesting; and harvesting to 12 months, which was when the land was fallow. Total emission of N_2O during the on-farm stage is 0.11 kg N ha^{-1}; or an emission factor of 0.02%, which was approximately 60-times less than the default value suggested by the IPCC for calculating N_2O emissions from cropped soils (1.25%) (Bouwman 1996; IPCC 1997). Since wheat production in south-western Australia depends on natural rainfall rather than irrigation, the use of power for irrigation pumping had not been considered in this LCA work.

Post-farm activities included transportation of one tonne of wheat from farm to local bin, storage of wheat and the transportation of wheat to port.

LCI: The development of life cycle inventory (LCI) was a prerequisite to assess the environmental impact. Figure 1 shows the simplified life cycle inventory diagram for one tonne of wheat transported to port.

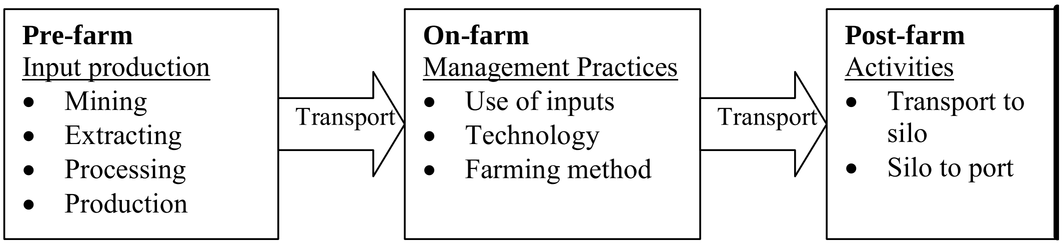

Figure 1. Life Cycle Inventory of wheat transported to port.

Pre-farm activities included the information on the production of inputs, such as mining, processing, production.

On-farm activities included the information on the use of inputs, such as N-fertiliser application, and diesel combustion in machinery for each of the three periods, and transportation for supplying inputs during these periods. Figure 2 shows the LCI of the production of one tonne of wheat. The numbers in brackets under the inputs column in the inventory are chemicals, energy, and machinery, which were required to produce one tonne of wheat from 28 kg of seed. The numbers under the outputs column of the inventory represent the emissions of GHGs (CO_2, CH_4, N_2O) due to farming activities in different periods of the product cycle. This information in Figure 2 was collected by interviewing farmers and the local people who were actively involved in wheat production in Cunderdin. Once the wheat is harvested, about 3% of the total yield was used as seed for sowing the following year.

Post-farm activities included two further stages, wheat storage (i.e. in bin and transportation of wheat to port, were included in the boundary (Figure 1).

Impact assessment: Two stages are involved for the environmental impact assessment of wheat production for pre-farm, on-farm and post-farm activities.

Stage 1: The input and output data in LCI were inserted into the Simapro (2006) software in order to assess GHG impact of wheat production. The input/output data of LCI were linked to relevant libraries in Simapro. The LCA Library is a database, which 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 LCI depend on the units of the relevant materials (i.e. kg, l, MJ, $ etc.) in Simapro or the libraries. For example, the farm machinery library has information on the environmental emissions for the production of a US$1 equivalent of machinery. Accordingly, input data for farm machinery for wheat production were converted into US dollar. Input data (e.g. $2US worth of machinery/tonne of wheat harvested) in the LCI was multiplied by the emission factors (e.g. 0.15 kg CO_2/US$ of machinery) in the farm machinery library in order to determine total emission due to use of an input (i.e. farm machinery) to produce 1 tonne of wheat.

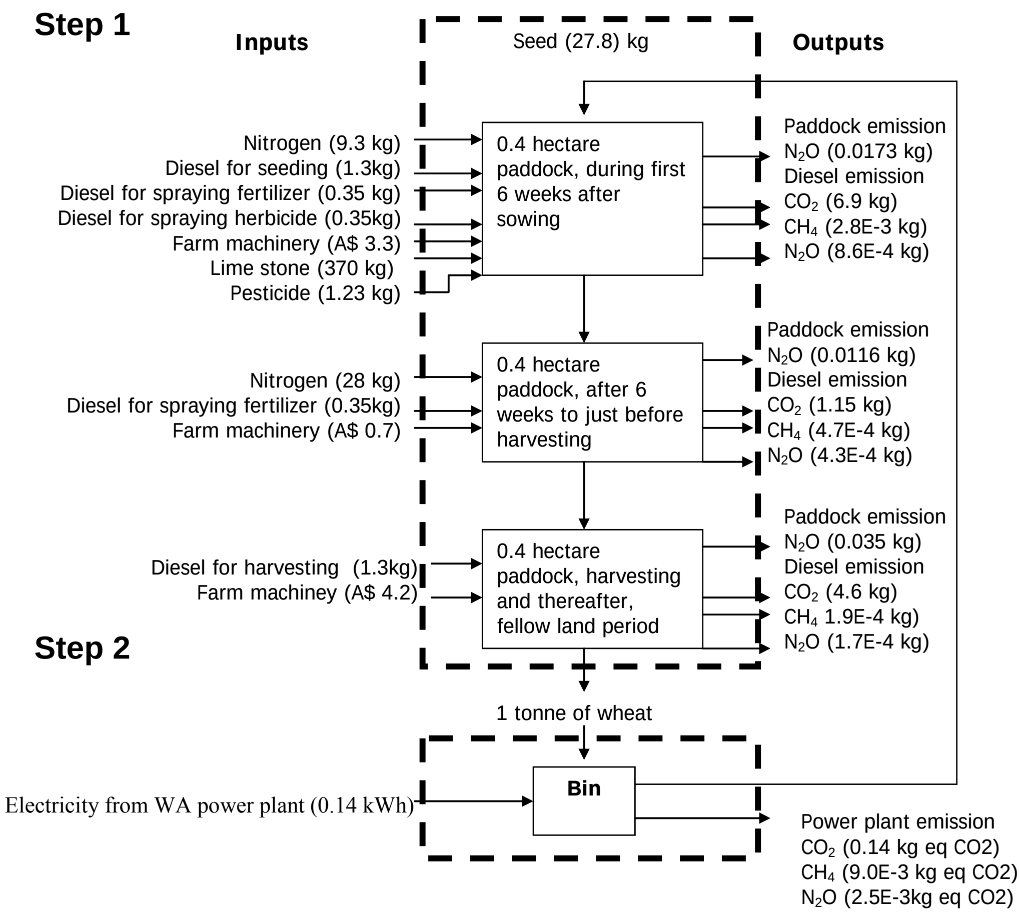

Figure 2. Life Cycle Inventory (LCI) of one tonne of wheat harvested for on-farm and post-farm stages.

Libraries for chemicals: In order to assess the impact of the production of chemical inputs, such as pesticides, limestone and urea, the Australian LCA database 2005 developed by Centre for Design, RMIT has been used (RMIT, 2005). The supply chain of urea and pesticide, including production and transportation to the point of use, was incorporated in order to assess the GHG effect during the pre-farm stage. For the Cunderdin site, a 30t articulated truck, which is widely used in the rural Australia, has to travel for 180 km to carry diesel and pesticide to the farm, and also travel 153 km to carry fertiliser to the paddock. The unit for transport library is tonne-kilometre (tkm). In this case, 0.4 tkm is required to carry 1 kg of pesticide or fertiliser for 400 km (i.e. 0.001 tonne x 4 km). The emission for GHGs, CO_2, CH_4 and N_2O are 0.076, 86 x 10^{-4} and 13x 10^{-4} kg/tkm, respectively (RMIT, 2005).

Farm machinery library: A USA input-output database was used to assess the GHG effect due to the manufacturing process of farm machinery used to produce one tonne of wheat (Suh, 2004). This database contains environmental emission data for the production of US$ 1 equivalent farm machinery. Table 1 shows the lifetime operational time of farm machines and their costs, which are required to determine the cost per hectare. The current price of farm machinery was deflated to 1998 price (in AUD) at 3% per year. Following this, the 1998 price of machinery in AUD/hectare has been converted into 1998 US dollar by multiplying by 0.6.

Table 1. Cost and operation of farm machinery for wheat production.

Name of machine	Operational time[1] hours/Ha	Life time (hours)[1]	Cost (AUD. 2006 price)	(AUD/Ha 2006 price)	(AUD/Ha, 1998 price)[2]
Seeder	0.12	8,640	90,000	1.28	1.04
Sprayer	0.02	8,640	70,000	0.16	0.13
Tractor (125 HP)for seeding	0.12	8,640	125000	1.78	1.45
Tractor (125 HP) for spraying	0.02	8,640	125000	0.29	0.23
Harvester	0.08	7,200	442,914	5.09	4.14

[1]CECP (2005)
[2]Have been deflated to 1998 price at 3% per year

Farm machinery operation library: The farm machinery (Table 6) consumes less than 500 MJ ha^{-1} and are regarded as light duty machinery (Nemecek *et al.* 2004). Therefore, the library for light duty agricultural machinery, developed by the Centre of Design, RMIT, was used to calculate the GHG effect potential of farm machinery operation. The emission factors for CO_2, CH_4, and N_2O are 0.0694, 2.8 E-6 and 2.6E-6 kg MJ^{-1}, respectively (RMIT, 2005).

Electricity library: The wheat bin consumes on average 0.14 kWh of electricity for every one tonne of wheat (Altham *et al*., 2004). The library for Western Australian electricity generation mix was used to calculate the GHG emission from the electricity generation (ESAA, 2003).

Libraries for storage and transportation to port: Storage time varies from a day to a year, however, an average emission factor for wheat storage has been taken from Altham *et al.* (2004), which is 4.57 kg of CO_2 equivalent per tonne of grain storage. Emission factors for transportation of wheat from farm to local bin, and from local bin to port considered the same emission factors which were used in the previous section. The distance from paddock to the bin in the nearby town of Cunderdin is 3 km, and the distance from the bin to Kwinnana Port in Kwinana is 180 km.

Stage 2: Once the inputs and out puts were linked to the relevant libraries, Simapro software was then run to calculate the GHG emissions. Firstly, the program sorted out the GHGs from the selected libraries. Secondly, the amounts of all selected gases were converted into kg of CO_2 equivalent using a conversion factor (Table 2) in order to obtain the CO_2 equivalent gas emission.

Table 2. Conversion factor for selected GHGs.

GHGs	Conversion factor	Unit
CO_2	1	kg CO_2 eq/kg of CO_2
CH_4	21	kg CO_2 eq/kg of CH_4
N_2O	310	kg CO_2 eq/kg of N_2O

Source: RMIT (2005)

A detailed damage assessment network of wheat production was developed by Simapro software which shows the contribution of all process, including mining, processing, transportation, utilisation of inputs to impacts.

Interpretation: This identifies the period or stages causing more GHG emissions than others, which were discussed in the following section. It enables LCA to expand the life cycle boundary by incorporating inputs and outputs in the supply chain of wheat production. It also checked the quality of data as to whether they are sufficient and useful to meet the goal of the LCA project.

Results and discussion

The environmental impact results which were obtained using a LCA software have been analysed in two steps. Firstly, LCA of on-farm activities has been carried out in order to determine the on-farm period emitting significant portion of GHGs. Secondly, LCA analysis has been conducted in more detail for the GHG emissions during pre-farming, on-farming and post-farming stages.

On-farm: The contribution of N_2O emission to GHG emissions due to one tonne of wheat production was analysed, using three boundary conditions. Table 3 shows the share of GHG emissions due to the emission of N_2O for the three boundaries. The first boundary included only direct impact of the use of inputs, such as diesel, fertiliser, machinery and pesticides. In this case, N_2O emissions contributed about 65% to total GHG emissions. The second boundary included the production as well as the use of inputs for producing one tonne of wheat. When the secondary boundary was included, the contribution of N_2O emissions to total GHG emissions was reduced to 20%. The third case considered the total supply chain, including transportation of inputs, their production and use for the production one tonne of wheat. In the total supply chain, N_2O emission contributed only 19% of the total GHG emissions. Thus it can be concluded that production and transportation caused greater impacts on N_2O emissions than inputs within the supply chain of one tonne of wheat production.

Data on the proportions of imported and locally manufactured fertiliser and pesticides were not available. Therefore, the GHG emissions of the transport of the inputs by ships from overseas sources was not assessed. The GHG emissions due to emission of N_2O was unchanged for three boundaries, because fertiliser application and land disturbance were the only sources of N_2O emission in the supply chain.

Table 3. Contribution of N_2O to the GHG emissions for three boundaries of LCI

Life cycle boundaries	Greenhouse effect (kg of CO_2 equivalent)		
	CO_2	CH_4	N_2O
Use of inputs only	14 (34%)	0.2 (0.5%)	27 (65.5%)
Production and use of inputs	103 (76%)	5 (4%)	27 (20%)
Transportation, production and use of inputs	111 (78%)	5 (3%)	27 (19%)

Note: numbers in the parenthesis represent the share of total contribution to GHG emissions.

Greenhouse gas equivalents due to the N_2O emission (27 kg of CO_2-equivalent) appears to be well below the value determined in the previous study (192 kg CO_2-equivalent) (Narayanaswamy and van Berkel 2005; Narayanaswamy et al. 2005). This is because the emission factors in the previous study were based on the USA situation, whereas the current LCA uses experimental field data for south-western Australia conditions. Also, as explained in the previous section, the proportion of fertiliser N applied that was lost as N_2O-N was extremely low (0.02%), less than the default value suggested by the IPCC (ICCP, 1997) for calculating N_2O emissions from cropped soils.

If we consider GHG emitted during the growth of the crop, CO_2 accounts for the significant portion of the total emission (Figure 3). This is because the use of diesel, pesticide and fertiliser is predominant in these periods. Nitrous oxide was the predominant GHG after summer rainfall which occurred following the harvesting period, and was likely to be due to increased nitrification activity following the rainfall. Methane emission was not found to be significant source of GHG emissions (2%), and was mainly derived from the diesel fuel combustion process. The GHG emissions in the production of one tonne of wheat from paddock to bin were 111 kg CO_2-equivalent of CO_2 (78%), 5kg CO_2-equivalent of CH_4 (3%) and 27kg of CO_2-equivalent of N_2O (19%) (Figure 3).

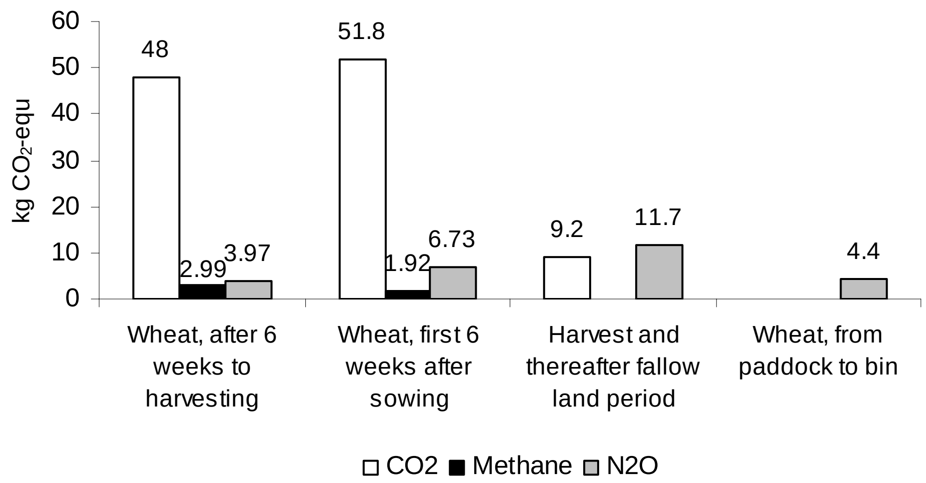

Figure 3. On-farm GHG emissions for one tonne of wheat (kg CO2-equ) for stages of on-farm production.

Pre-, on- and post-farm LCA: The equivalent of 171 kg of CO_2 was produced during the production and delivery of one tonne of wheat port (Figure 4). Carbon dioxide contributed 128 kg (75 %), CH_4 contributed 9 kg CO_2-equivalents (5 %)and N_2O contributed 34 kg of CO_2-equivalents (20 %). Pre-farm, on-farm and post-farm stages accounted for 58%, 24% and 18% of the total emissions, respectively.

The greatest amount of CO_2 was emitted during the pre-farm stage (i.e. 94.7 kg of CO_2–equivalents), which included the production of diesel, fertilisers, pesticides and machinery as well as their transportation to the point of use (the paddock). By contrast, N_2O was mainly produced during the on-farm stage, which accounted for 77% of the total N_2O emission. The remaining N_2O was emitted in the post-farm stage via transportation using an articulated truck (13×10^{-5} kg N_2O per tonne-km); and was a result of the significant transport distance, and the high global warming impact of N_2O (310 kg CO_2–equivalents per kg of N_2O). Although articulated trucks were also used to carry inputs to the paddock, the impact of N_2O during the pre-farm period was low because the mass of diesel, fertiliser and pesticide, was very small (i.e. between 1 to 30 kg) compared to one tonne of wheat travelling the same distance to the port.

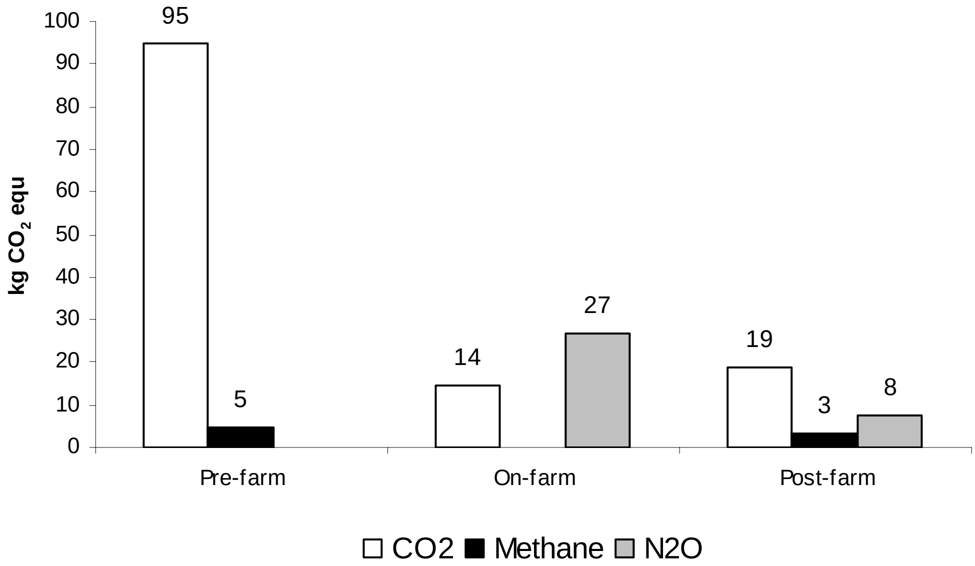

Figure 4. GHG emissions (CO_2 equivalents) during pre-farm, on-farm and post-farm activities.

The CO_2 emissions potential of the production and utilisation inputs for pre-farm, on-farm and post-farm stages are shown in Figure 5. Since pre-farm stage was an input to on-farm operation, their combined impact was assessed. The production of fertiliser accounted for a significant portion of the impact for pre-farm and on-farm activities for wheat production. Emissions from farm machinery operation and from the paddock were higher than emissions from the manufacturing process of inputs (e.g., farm machinery, pesticide, limestone etc). Transportation had been found to be predominant during the post-farm stage.

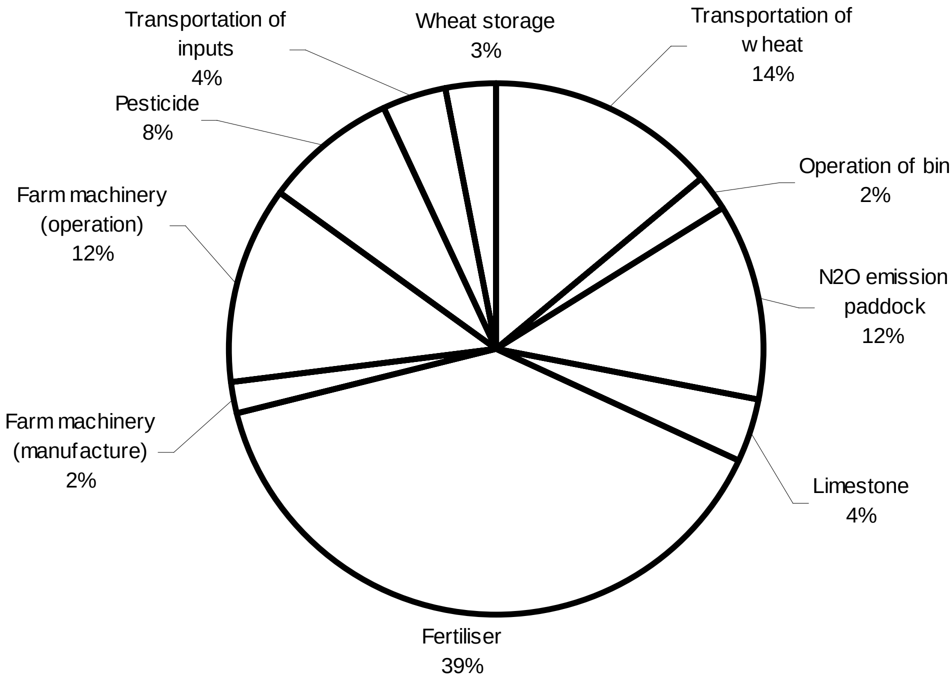

Figure 5. Percentage contributions of GHG emissions (CO_2 equivalents) in terms of inputs and outputs for the grains industry.

Conclusions

The equivalent of 171 kg of CO_2 was produced during the production and delivery of one tonne of wheat to the port. The pre-farm stage, which included environmental impact of the production of inputs, such as mining, processing, and transportation to the point of use, accounted for the significant portion (58%) of the total global warming potential, followed by on-farm (24%) and post-farm (18%) stages. The production of fertiliser accounted for a significant portion of the impact for pre-farm and on-farm activities for wheat production, while GHG emissions from transportation have been found to be predominant during the post-farm stage. Further investigation of approaches for decreasing GHG emissions during pre-farm and post-farm activities are now required in order to reduce the impact of Australian grain production on GHG emissions.

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