LIFE CYCLE ASSESSMENT OF A EPRESENTATIVE DAIRY FARM WITH LIMITED IRRIGATION PASTURES

Guangnan Chen[1], Simon Orphant[1], Sarah J. Kenman[2]
and Robert G. Chataway[2]
[1]Faculty of Engineering and Surveying, University of Southern Queensland,
Toowoomba, Queensland 4350. Email: chengn@usq.edu.au
[2]Queensland Department of Primary Industries and Fisheries, Mutdapilly Research
Station, MS 825 Peak Crossing, QLD 4306.

SUMMARY

The environmental impacts and the sustainable development of agricultural activities have been identified as a significant national issue. This paper presents an initial assessment of the life cycle impacts of a representative dairy farm with limited irrigation pastures using SimaPro. The functional unit is defined as the production of one litre of raw milk leaving at the farm gate. The input data is described and the limitation of current investigation is identified. It is shown that for this type of farm, most of the environmental impacts (based on the combined single-score method) are due to the energy use by irrigation pump (33%), the use of the urea fertilizer (27%), and the cow methane emissions (21%). Therefore, future improvements should focus on these three factors. It is also found that the contribution to environmental impact from phosphorous fertilizer, potassium fertilizer, truck and tractor are all relatively small, being 1.22%, 0.11%, 3.47% and 2.24% respectively. In terms of the single-issue indicator of climate change, the contribution from the cow methane emissions is very significant at 76.2%.

Keywords: LCA, milk, pasture, dairy farm, SimaPro, Australia

1. INTRODUCTION

Milk, a source of 15 essential nutrients, energy and large volumes of water, has an outstanding value for good human health. Production of milk and associated dairy products is a very important industry in Australia. At present, it is estimated that Australia has about 13,000 dairy farms, owning 2.2 m cows, and producing 11 b litres of milk a year. Australia is now also the world's third largest dairy exporter, with an overall market share of 15 per cent, valued at A$3 billion per annum [1].

With recent rapid change and deregulation of the dairy industry and increased customer demand for environmentally-friendly green products and more transparent environmental information, increasing pressure is put on the dairy farmers to improve their environmental performance and sustainability. Unfortunately, it has been found that between 1990 and 1999, there has been a 28% rise in emissions from dairy cattle, due to increased livestock numbers and an increased use of fertilizers [2]. Furthermore, dairy farms in Australia are also significant consumers of natural resources, particularly water. It is estimated that dairy farming uses 17% of total water used in agriculture, which in turn represents 67% of total water consumption in Australia [3]. This is particularly a challenge for the dry continent of Australia, which frequently experiences drought and water shortage. Another significant side effect of long-term irrigation practice is that it may also lead to serious land and environment degradations, such as salinisation.

The environmental impact and the sustainable development of agricultural activities have now been identified as a significant national issue by the government [4]. Australia currently has the highest per capita greenhouse gas emissions (27.2 t) in the world [5].

There are already some studies carried out on the environmental impacts of dairy farms, mostly in European countries such as Sweden and Spain [6-8]. These researches provide some insight into the environmental impacts of their particular situations. However, because Australia has a unique land and environmental condition, significantly different energy structure (92% of its electricity is generated from coal) [9], and long-distance transport requirement, there is a strong need for research to be conducted in the Australian context, to improve its environmental performance standard.

2. LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is an internationally recognized method for compiling and assessing environmental information for products. By identifying where the environmental impacts and damages take place, it is also the first step towards sustainable development.

LCA has already been successfully applied to a number of specific industries and products, including the building construction industry [10]. However, because of the complex and often multi-functional nature of agricultural systems, until recently, there has been little research into the application of LCA in agriculture. Particularly, there are still significant uncertainties associated with some of the impact calculation methods, and the quality of input data. Applying LCA technique to unique Australian conditions would pose further challenges.

LCA is achieved by identifying and profiling all the resources (energy, land, water and other materials) used, and wastes released to the environment during its whole life cycle. An LCA analysis generally consists of following four steps [11]:

- Initiation (goal and scope definition)
- Inventory analysis (identifying all relevant input and output items);
- Impact assessment (quantification and evaluation of impacts on ecosystems, human beings and resources use by conducting a rigorous input and output flow balance analysis);
- Interpretation and improvement assessment (evaluation of options to reduce environmental loads).

In comparison with most of the current research which typically only focuses on one or two aspects of environmental impacts (eg greenhouse gas emissions), LCA has the advantage of providing a rigorous, comprehensive, and multi-dimensional analysis of all relevant factors (eg, to include all the influences of energy uses and greenhouse gas emissions, land salinisation, acid rain, waste and toxin releases, natural resource depletion and human health). It is therefore potentially a very useful and powerful tool for the comprehensive evaluation of the environmental impact of complex systems, such as agricultural activities. A comprehensive LCA analysis would in particular have the advantage of being able to quantify the magnitude of potential environmental saving in each (environmental) category, and to avoid the pitfall of just shifting from one category to another category [10].

3. RESEARCH OBJECTIVES AND METHODS

3.1 Research objectives

The objectives of this research are:

1. to study the potential of adopting the LCA method to Australia’s dairy industry;
2. to characterize the environmental impact of a representative farm using one particular farming method;
3. to identify the hot spots and potential improvements of farm operations, in order to provide a scientific basis for the optimum use of natural resources, and the optimum selection of farming methods.

3.2 Research method and data collection

In this project, a basic model incorporating the major inputs and outputs is first set up. A simplified hypothetical farm is assumed, representing a typical dairy farm in subtropical Queensland. Most of the farm operation data for this study is collected from the research at Mutdapilly Research Station, Queensland Department of Primary Industries and Fisheries (DPIF), which has an active and extensive program of monitoring the performance of various types of dairy farms in Australia. Their recent research has also indicated that northern Australian dairy farms may be broadly characterized into following five types of production systems [12]:

- Rain grown pastures (tropical pastures plus forage oats)
- Limited irrigation pastures (rain grown tropical grass pastures plus annual ryegrass)
- Limited irrigation crops (forage crops plus annual ryegrass)
- High irrigation (irrigated annual and perennial temperate pastures plus summer forage crops)
- Feedlot (irrigated maize silage, lucerne hay and barley silage).

The farm in this research belongs to the second type of production system.

In this research, the software used is SimaPro 5.1 [13], which is currently one of the most widely used LCA software in the world. The data library used is Australian LCA Data Inventory which was initially generated in 1998. This data was subsequently updated and added in 2002. The farm system is also modeled as an industrial system [13], which implies that the impact of land-use will be taken into account. The fertilizer substances leaching into deeper soil and water or that evaporate can also be considered by this method.

3.3 Functional unit

Because of the scope of this study, the initial focus is on the farm operation and pasture production, as it has been found that most impacts take place during the cow milk production phase [14]. It has been found that pasture production is often the main contributor for environmental impacts and is more significant than that in the milk power production phase. The functional unit in this project is defined as the production of one litre of raw milk leaving at the farm gate.

A similar definition of the functional unit was also adopted by other researches [6,7,14].

3.4 Chosen impact categories

Environmental impacts may occur at three levels: global, regional and local levels. In this study, the environmental impact damage model used is Eco-indicator 99 (E) AU/Europe EI 99E/A, which calculates and characterizes the environmental damages and resource uses from the Egalitarian perspective (ie, with a very long-term view). Using a different calculation method such as Eco-indicator 99 H/I (which adopts a different assessment timeframe) may lead to a different result [15].

The three environmental impact damage categories considered by this paper are:

1. Resources: fossil fuels, land, and mineral uses;
2. Ecological quality: climate change, acidification/eutrophication, radiation, depletion of stratospheric ozone, and eco-toxicity;
3. Human health: carcinogens, and respiratory organics and in-organics.

To calculate the overall single-score impact, the average weighting method is adopted [13], with the Resources use (0.5 weighing, or 20% of total impact), Ecological quality (1.0 weighing, or 40% of total impact), and Human health (1.0 weighing, or 40% of total impact). It is realized that this method of calculating single-score impact is somewhat subjective. The normalization results given by Eco-indicator 99 could also potentially overstate or underestimate the impact for Australia, as Australia as a whole has a lower population density and a more vulnerable ecosystem.

Because of the limitation of the current software and the present state of science, the environmental impacts of salinity, soil quality, water use and animal welfare are not modeled in this project. Many of these impacts are particularly relevant to agricultural sector, but are highly variable and site-specific, depending on local and regional factors.

4. FARM INVENTORY AND DESCRIPTION

The hypothetical farm is located in the high rainfall environment of southeast Queensland (state) in the Gympie district. Mean annual rainfall for the region is 1250 mm.

The farm is assumed to have 100 cows and occupy 50 ha of land area. The stocking density is therefore two cows per ha.

All feed input to the cows is assumed from pasture production, so no any form of artificial drying, silage and processing is performed. All the manure produced by the animals is also assumed to remain on-site and be used as fertilizer. No soil cultivation is carried out.

In the summer season, kikuyu grass (*Pennisetum clandestinum*) is grown with a yield 15t DM/ha. No irrigation is involved. In the winter season, ryegrass (*Lolium* spp.) is over-sown into kikuyu pasture, with a yield of 10t/ha. Irrigation is then required. However, only 20 ha of land is used. So the total annual winter pasture yield is 10*20=200 t, and the total annual summer pasture yield is 15*50=750 t. The feed density is therefore 9.5t DM per cow per annum. For this dietary intake, each cow is assumed to produce some 145 kg of methane emission per annum.

The milk production is assumed to be 3,750 litre per cow per annum. This is equal to 12.5 litre per day, assuming 300 days of milk production. This milk yield is relatively low compared to farms which use a higher energy density ration.

The electricity use for irrigation is determined by both the animals drinking needs (assumed as 65 L per cow per day or total 65*100cows*365 days = 2.372 megalitre) and for the pasture production. Overall, it may be assumed that the total amount of irrigated water is equivalent to 500 mm of rainfall or 0.5m*20ha*10000 m^2/ha = 100,000 m^3 = 100 megalitre (No irrigation is involved in the summer season for this farm). Based on the current average industry data, this would require pumping electricity energy use of 42,000 kWh.

The second source of electricity requirement on the farm comes from the temporary cool storage and milking machines. Based on the current average industry data, the total electricity use for the milking machines and temporary cool storage operations for this farm is estimated as 13,200 kWh, assuming that the milk is kept on farm for one day only.

With regards to the fertilizer requirements for pasture production, we have assumed that it would require 500 kg/ha of ammonia-urea (which contains 46% nitrogen) for the summer season (all 50 ha) and 700 kg/ha of application for the winter season (20 ha). This works out that the total averaged urea usage is 780 kg/ha per annum or 39,000 kg for the whole farm. Similarly, for the phosphorus and potassium applications, the summer season may be assumed as 15 kg/ha for all 50 ha while in the winter season only 20 ha is covered, so that the total annual phosphorus application is 15kg*50ha (summer) + 15kg*20ha (winter) = 1050 kg. The total annual potassium application is 30kg*50ha (summer) + 30kg*20ha (winter) = 2100 kg.

To spread fertilizer and grass seeds, some tractor operations will be necessary. Based on the current average industry data, it is assumed that ten operations would be required each year and each such operation would use 2L of diesel/ha. The fertilizer, grass seeds and other goods are also assumed to be transported from a distance of 200 km, with a load efficiency of 50%. This implies that the truck has an empty load for the return trip.

In this investigation, no pesticide use has been assumed. Pesticide use is often related to the production of supplementary feeds such as grain. These supplements are not required for the present type of farm. It is also found that the impact of pesticides is generally small in comparison with fertilizers which contain heavy metals [16].

Table 1 in the next page summarizes the total resources used and outputs produced at this farm on an annual basis.

Total cattle number	100
Land use area (ha)	50
Irrigation water (megalitre)	100
Pasture production (kg dry matter)	950,000
Milk production (litre)	375,000
Irrigation pumping electricity use (kWh)	42,000
Electricity use due to milking machines and temporary cool storage (kWh)	13,200
Urea fertilizer use (kg)	39,000
Phosphorus fertilizer use (kg)	1,050
Potassium fertilizer use (kg)	2,100
Pesticide use (kg)	0
Tractor diesel fuel use (litre)	1,000
Truck use (ton∗km)	20,000
Cow methane emissions (kg)	14,500

Table 1 Total resources used and outputs produced per year at the hypothetical farm

5. PROCESS FLOWCHART AND SYSTEM BOUNDARIES

The process flowchart describing the phases of the life cycle of milk production is shown in Fig.1, which include all the major uses of the materials, energy and other resources. In particular, processes that have been included in this model are as follows: the electricity power used in milking and temporary cool storage, the cow itself (pasture to milk phase, which allows us to model the cow methane output), and the pasture production (this models the inputs of fertilizers, water, and tractor and truck uses). The fertilizer and electricity generation data is taken from Australian LCA Data Inventory as supplied by the RMIT University in Melbourne.

As other researches, buildings and machinery have been excluded in the present study. Also excluded are medicines, washing detergents and minor products such as disinfectants, salt for cows, etc. Treatment of cow solid waste and the effect of the fertilizer substances leaching into the soil and water systems are also not modeled.

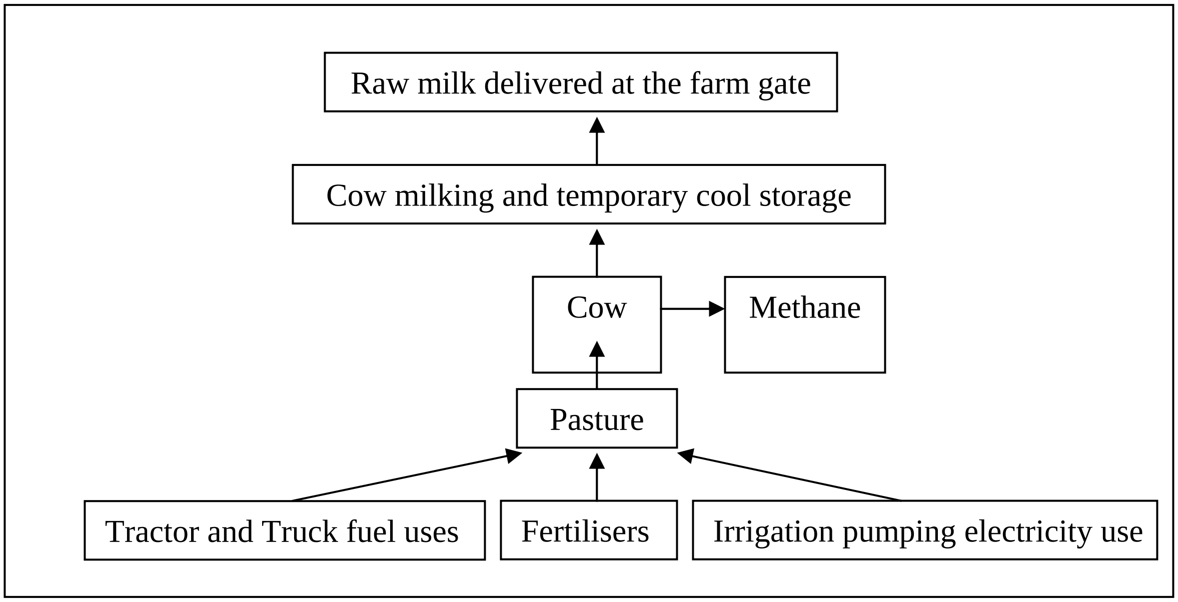

Fig.1 Process flow chart for farm milk production

6. IMPACT ASSESSMENT

6.1 Overall single-score impact for the complete process

Fig.2 shows the overall impact (single-score) presented in a tree for major farm inputs. It can be seen that as far as the farm input is concerned, the cow and pasture production phases produce most of the environmental impact (88%) in comparison with that due to the milking machines and milk temporary cool storage (12%). This illustrates that future improvements of the farm operation should focus on the cow milk production phase which includes the energy use by irrigation pump (33%) and the manufacturing of the urea fertilizer (27%). It is also noted that the large difference between Cow (88%) and Pasture (67%) in Fig.2 is attributed to the significant methane emissions from the cow digestion system. The contribution to environmental impacts from phosphorous fertilizer, potassium fertilizer, truck and tractor are, however, all relatively small, being 1.22%, 0.11%, 3.47% and 2.24% respectively. Emissions of the potent greenhouse gases methane and nitrous oxide have previously been identified as the critical parameters when assessing agricultural production [6,7,8,17].

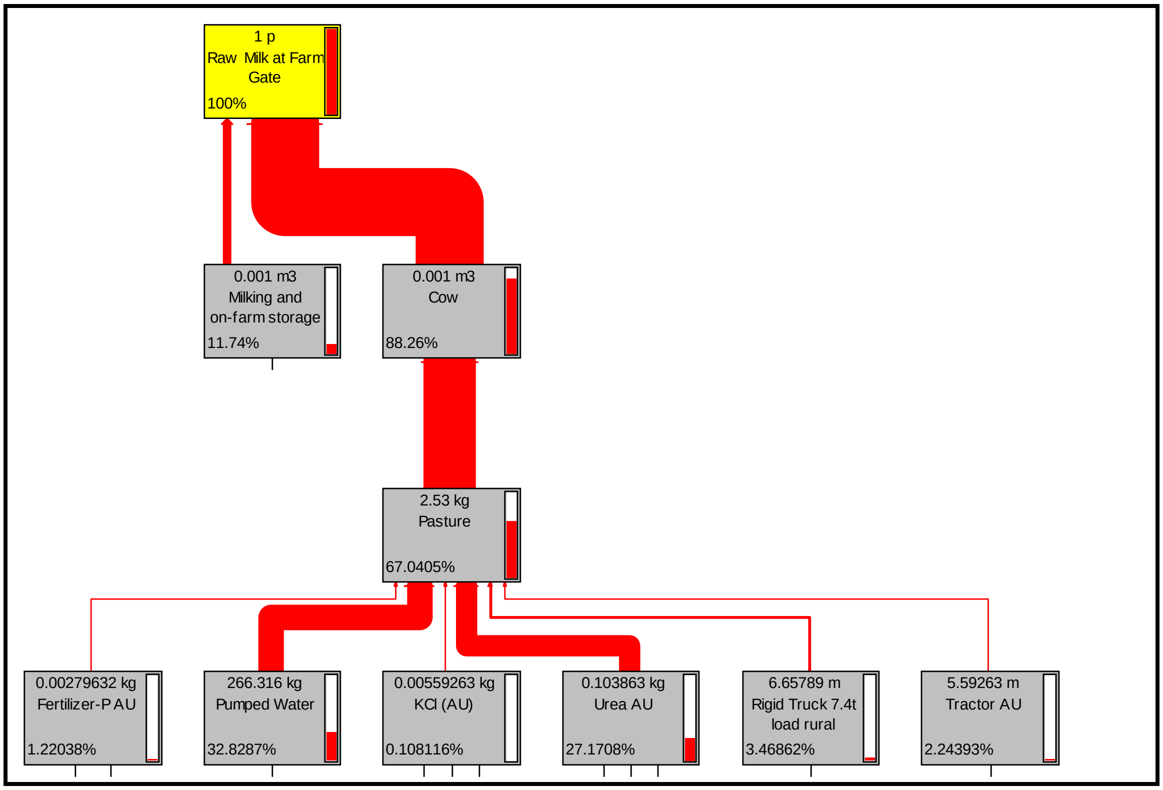

Fig.2 Overall single-score impact presented in a tree for major farm inputs

6.2 Individual impact indicators and climate change impact for the complete process

Figures 3 and 4 show the detailed individual impacts in the farm operations. It can be seen from Fig.3 that although the fossil fuel use in the milk storing phase (milking and milk temporary cool storage) is 13%, its impact on the overall climate change is reduced to 4%. This is attributed to the significant methane emissions from the cow digestion system. In fact, as it can be seen in Fig.4, in the cow milk production phase and in the category of climate change, the damage due to cow methane emissions is the dominant factor (80%), compared with that in the pasture production phase. This illustrates that in addition to above-mentioned factors of the energy use by irrigation pump and the manufacturing of the urea fertilizer, the improvements of feed diet strategy could also be very important [6,7,18]. As can be seen in Fig.5, the contribution from the cow methane emissions to the climate change indicator in the complete process is equal to 95.9% - 19.7% = 76.2%, which is extremely significant. This result is also consistent with the industry observation that methane emissions from cows contributes between 60~80% of total dairy farm greenhouse gas emissions [19], as it has 21 times the global warming potential of carbon dioxide.

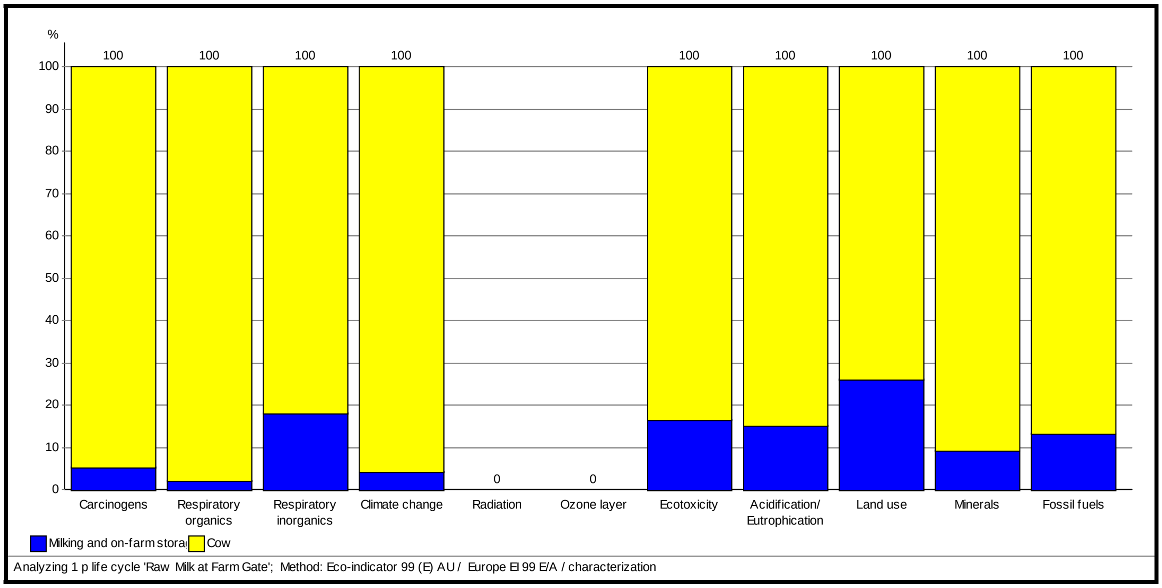

Fig.3 Individual impacts in the cow milk production phase and in the milking and milk temporary cool storage phase

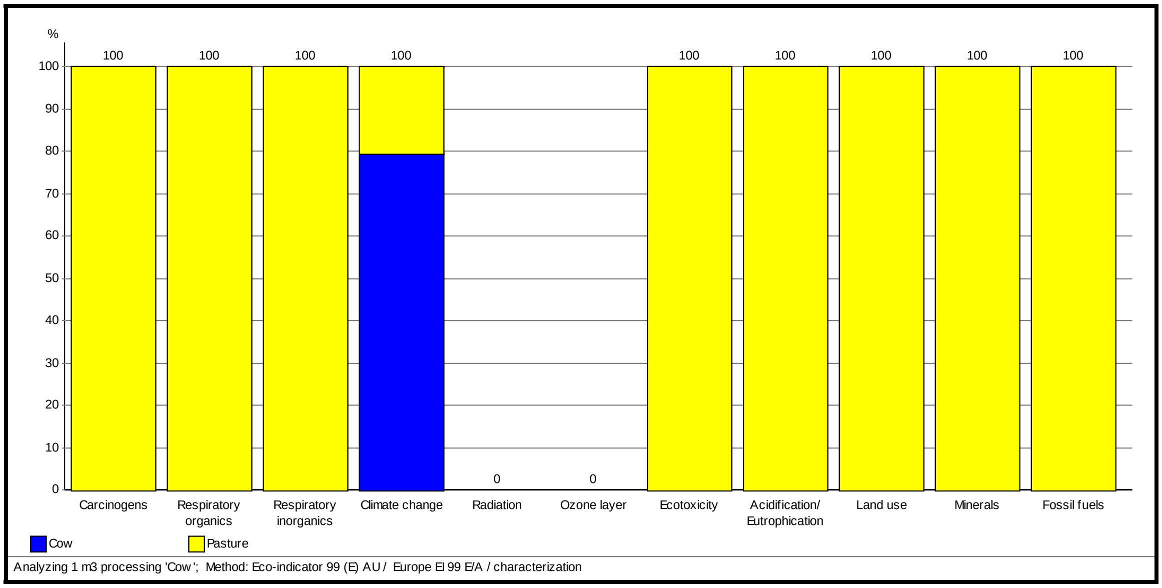

Fig.4 Individual impacts in the pasture production phase and that due to the cow methane emissions

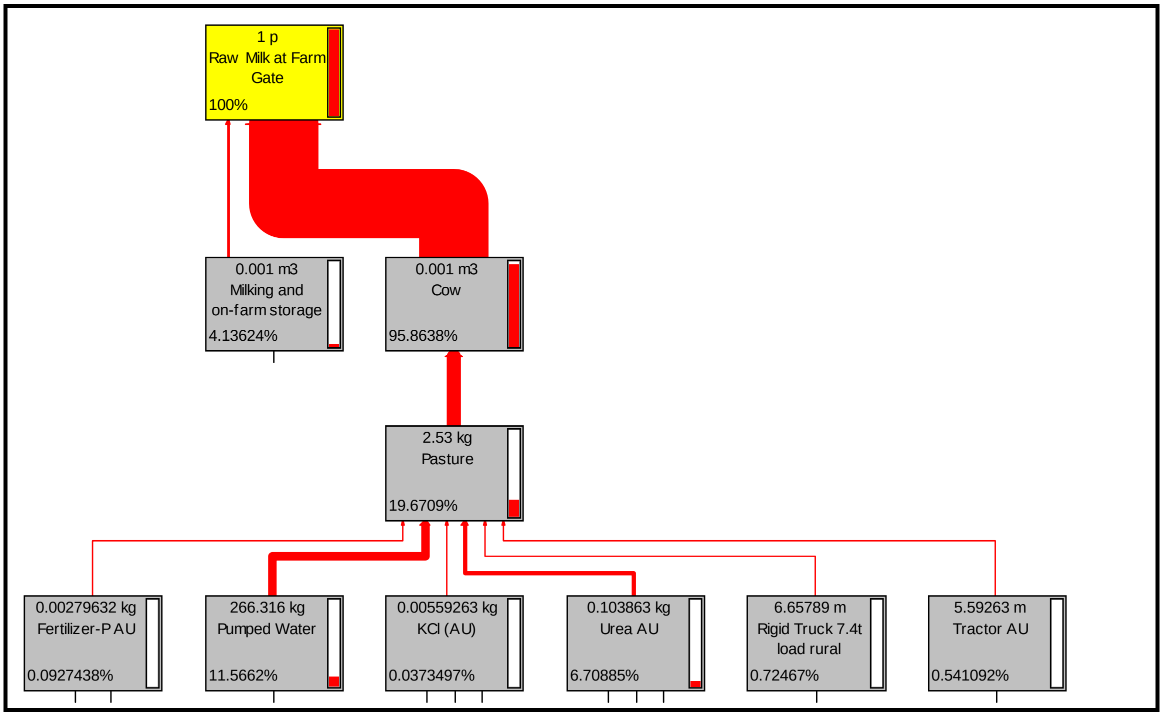

Fig.5 Impact on climate change presented in a tree for major farm inputs

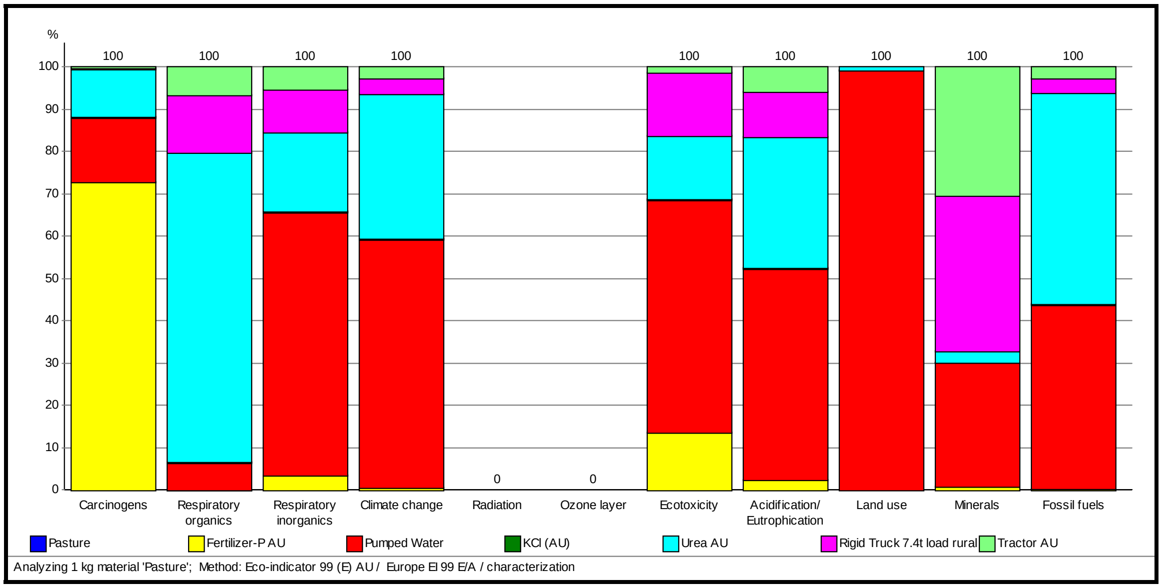

Fig.6 Individual impacts in the pasture production phase

6.3 Environmental impacts in the pasture production phase

In the pasture production phase, it can be seen from Fig.6 that in the fossil fuel category, electricity pumping energy takes up to 43% of primary energy use, while its contribution to the climate change rises further to 59%. This difference may be attributed to the use of a high proportion of coal for electricity generation in Australia and Queensland, while a significant proportion of energy use for manufacturing the fertilizer comes from the more “clean” natural gas. It also demonstrates the great importance of improving the irrigation pumping efficiency and the electricity generation efficiency, and raising the proportion of renewable energy in Australia. It is noted that the assumed energy use for water pumping in this particular farm is fairly high, as the model intends to represent the current averaged performance in the "real" farms. Through better management and equipment selection, this efficiency could be improved considerably. Water pumping in Queensland would also typically use spray irrigation method, which requires higher energy input as opposed to more water-wasting flood irrigation method which is more common in other states and which would use little electricity.

From Figure 6, it can also be seen that a significant proportion of the environmental damage due to fertilizer applications come from nitrogen urea, which is causing 34% of the total climate change, 31% acidification/eutrophication, and 50% of fossil fuel use in the pasture production phase. This may illustrate the potential opportunity of adopting low-input organic farming method in Australia where no synthetic fertilizer/chemical is used [6]. Acidification and eutrophication of river/land systems is a particular concern in Queensland and Australia, because of its potential impact on the health of vulnerable Murray-Darling river systems and world heritage Great Barrier Reef marine park.

For the general human health category, it can be seen from Fig.6 that the nitrogenous fertiliser (Urea) contribute some 73% of the impact to the respiratory organics, while fertiliser P (phosphorus) also contribute some 73% to the effect of carcinogens. Fertiliser use is therefore an important factor when assessing the environmental impact in these categories [6,7,8]. However, it appears that in all environmental and resource categories, the contribution from fertiliser K (potassium) is minimal.

For the machinery use, from Fig.6, it can be seen that tractor diesel use contributes 30% of the impact to the mineral use. It is also a significant contributor to respiratory organics and inorganics, as well as climate change.

Truck use contributes 37% of the impact to the mineral use. It is also a significant contributor to respiratory organics, eco-toxicity, as well as acidification/eutrophication (11%).

4. LIMITATIONS OF PRESENT STUDY AND FUTURE RESEARCH

As can be found from above, in addition to the limitations of the software and the impact assessment method, there are still following limitations in the present study, which include:

- The model is based on a simplified hypothetical farm with limited irrigated pasture. It does not take account of other feed supplements such as grain and other concentrates which are common in intensive types of farms.
- The model has assumed that no any form of artificial drying, silage and processing is involved. These processes may introduce additional environmental impacts into the dairy farming process.
- The model has also not allowed the allocation of co-product such as cow meat. In other research, this would typically give an overall allocation of 85-87% to milk and 13-15% to meat [6,7,20].
- The contribution from a number of small items has been ignored. These include the environmental impact due to the refrigerant for the milk cool storage, and the energy involved in the production of pasture seed.

In terms of future research, it is apparent that more model sensitivity studies will need to be carried out, in order to quantify the economic and environmental consequences of changing farm operation practices. Some model parameters may be varied, which include the stocking density, herd size, the amount and quality of supplementary feed, and production types and regions. It is also necessary to add the other processes, including the feed supplement and animal waste treatment. These exercises would increase the accuracy and overall confidence of the present model. The comparison of different farm types will also help to identify the relative advantages and trade-off of alternative production systems.

5. CONCLUSIONS

This paper has presented a LCA model based on a representative dairy farm located in a high rainfall environment in Southeast Queensland. SimaPro 5.1 has been used. It has been shown that the model is able to simulate the dairy farming process and produce realistic results which is consistent with the relevant industry experience and other research. This demonstrates that SimaPro and LCA is a useful tool in agricultural environmental assessment and it can be used to indicate and aid understanding of the environmental impact of agricultural activities.

Preliminary results for this particular type of farm indicate that major impacts to the environment are due to the energy use by the irrigation pump, the use of the urea fertilizer, and the cow methane emissions. Therefore, future improvements should focus on these three factors, with the key areas being fertiliser management, particularly the use of urea; and water management, particularly pumping and irrigation efficiency. The potential opportunity of raising the proportion of renewable energy for electricity generation, adopting organic farming methods, and the improvement of feed diet strategy also need to be investigated.

The research highlights the need for further development of the impact assessment method for the agricultural sector. In the future, LCA may also be combined with Life Cycle Costing (LCC) to produce a complete tool for both economic and environmental assessments. Use of real farm field data may also be desirable.

ACKNOWLEDGEMENTS

The authors wish to thank the financial support provided by the University of Southern Queensland (USQ) and the National Centre for Engineering in Agriculture (NCEA) for this project. We also wish to thank Dr Richard Eckard of the University of Melbourne for providing the advice on the level of cow methane emission for this particular type of diet. Tim Grant of Life Cycle Strategies Pty Ltd and RMIT University in Melbourne provided useful discussions on the use of SimaPro software.

REFERENCES

1. Australian Bureau of Statistics website, http://www.abs.gov.au/Ausstats/abs@.nsf/0/B006A83A9127B0F5CA256DEA00053965?Open, Accessed at 22 October 2004.
2. Australian Greenhouse Office website, http://www.greenhouse.gov.au/agriculture/framework/object23.html/, Accessed at 22 October 2004.
3. Australian Bureau of Statistics website, http://www.abs.gov.au/Ausstats/abs@.nsf/0/a7f8ae8188119911ca2568d40004eaf7?OpenDocument, Accessed at 22 October 2004.
4. Commonwealth Department of Education, Science and Training website, http://www.dest.gov.au/priorities/ Accessed at 22 October 2004.
5. Turton, H, "Greenhouse gas emissions in industrialized countries - where does Australia stand?", Discussion Paper 66, *The Australia Institute*, Canberra, June 2004, ISSN 1322-5421.
6. Cederberg, C., Mattson, B. "Life cycle assessment of milk production - a comparison of conventional and organic farming". *Journal of Cleaner Production*, 2000;8, pp.49–60.
7. Hospido, A., Moreira, M.T., Feijoo, G. "Simplified life cycle assessment of galician milk production", *International Dairy Journal*, 2003;13, pp.783–796
8. De Boer, I.J.M., "Environmental impact assessment of conventional and organic milk production". *Livestock Production Science*, 2003;80, pp.69-77.
9. Department of the Prime Minister and Cabinet website, http://www.dpmc.gov.au/energy_future/chapter8/4_greenhouse.htm, Accessed at 22 October 2004.
10. Lippiatt, B.C. and Boyles, A.S. "Using BEES to select cost-effective green products", *International Journal of Life Cycle Assessment*, 2001, Vol.6, No.2, pp.76-80.
11. Narayanaswamy, V., Altham, J., Van Berkel, R. and McGregor, M., "A primer on environmental life cycle assessment for Australian grains", *Curtin University of Technology*, 2002, ISBN 1 74067 192 9.
12. Callow, M.N., Kenman, S.J., "Evaluation of the water use efficiency of dairy production using crops and pastures", *4th International Crop Science Congress*, 2004, Brisbane, Australia.
13. PRé Consultants, http://www.pre.nl/
14. Hamilton, A., Wegener, M., Dart, P. and Silvey, B., "Life cycle assessment of milk production systems in south Queensland", *Annual Conference, Australian Agricultural and Resource Economics Society*, January 2000, Sydney,

Australia.

15. Dreyer, L.C. Niemann, A.L., Hauschild, M., "Comparison of three different LCIA methods: EDIP97, CML2001 and Eco-indicator 99 - does it matter which one you choose?", *International Journal of Life Cycle Assessment*, 2003, Vol.8, No.4, pp.191-200.
16. Hellweg, S., Geisler, G. (ed), "Life cycle impact assessment of pesticides", *International Journal of Life Cycle Assessment*, 2003, Vol.8, No.5, pp.310-312.
17. Wells, C. "Total energy indicators of agricultural sustainability: dairy farming case study", *Technical Paper 2001/3*, Ministry of Agriculture and Forestry, New Zealand, ISBN 0 478 07968 0.
18. Wilson, B. "Managing carbon in rural Australia", *Natural Resource Management*, 2002, Vol.5, No.2, pp.7-15.
19. Innovate Australia, http://www.innovateaustralia.com/newsletter/v1_3/greenhouse.htm, Accessed at 22 October 2004.
20. Cederberg, C., Stadig, M. "System expansion and allocation in life cycle assessment of milk and beef production", *International Journal of Life Cycle Assessment*, 2003, Vol.8, No.6, pp.350-356.