# ROLE OF LIFE CYCLE ASSESSMENT IN AGRICULTURE FOR REALISING MARKET OPPORTUNITIES AND ENHANCING ON-FARM EFFICIENCY

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**Abstract**

Life Cycle Assessment (LCA) is a key tool for evaluating the resource inputs and environmental emissions throughout the life cycle of a product so that the key 'hot-spots' can be identified and the most effective options for improvement defined. It covers a range of environmental issues and not just greenhouse gas (GHG) emissions.

An increasing number of major supermarket chains throughout the world are looking at either eco-labelling of products or requiring suppliers to have determined their environmental emissions (e.g. the carbon footprint of products) and have a reduction plan over time. At a national level, some governments have commissioned work to examine how reduced environmental targets can be achieved. For example, the United Kingdom has indicated the need for major cuts in GHG emissions and studies have examined how low they can go by modifying the food system. An LCA study revealed the need for a combination of dietary change, technical efficiency improvements, reduced waste and less fossil fuel use. The largest single dietary-change reduction was from a no-meat diet.

Identification and development of low environmental impact agricultural systems have potential to provide a marketing advantage or opportunity in high-returning environmentally-sensitive markets. Studies in NZ on the carbon footprint and eutrophication potential of some meat and milk products have shown dominance of the farm production stage to total emissions, a low contribution from shipping to overseas markets and relatively low total emissions compared to some overseas production systems.

Detailed analyses of individual dairy farms within regions of New Zealand have indicated an approximately two-fold variation in carbon footprint, with decreasing carbon footprint being correlated with reduced nitrogen leaching and increased profitability. This highlights the potential for improving environmental efficiency on some farms. An LCA approach is essential to accurately determining the whole system environmental efficiency, particularly where there is high use of external farm inputs such as fertilisers and brought-in supplementary feeds.

## Introduction

The expected global population increase to over nine billion people by 2050 highlights the increasing requirements for food in future, all from a fixed land resource. As well as this need for increasing agricultural production there is a growing awareness and concern in developed countries about our insatiable use of non-renewable resources (e.g. fossil fuels, minerals) and the impacts of agriculture on the environment. International interest in this area is increasing and the Food and Agriculture Organisation has recently initiated a programme on defining and promoting increased resource use efficiency for global agriculture. Efforts such as these recognise that there are contributors to the use of resources and environmental emissions along all stages of the supply chain.

Life Cycle Assessment (LCA; Guinée et al., 2002) is a key tool for evaluating whole-system environmental efficiency. It enables evaluation of the resource inputs and environmental emissions throughout the life cycle of a product so that the key 'hot-spots' can be identified and the most effective options for improvement defined. This starts from the extraction of raw materials and includes all aspects of processing and transportation. Figure 1 gives an example for lamb covering the various life cycle stages including the final consumption and waste stages, i.e., from the "cradle-to-grave" [many agricultural studies have been confined to the "cradle-to-farm-gate" stage and examples of these are discussed later].

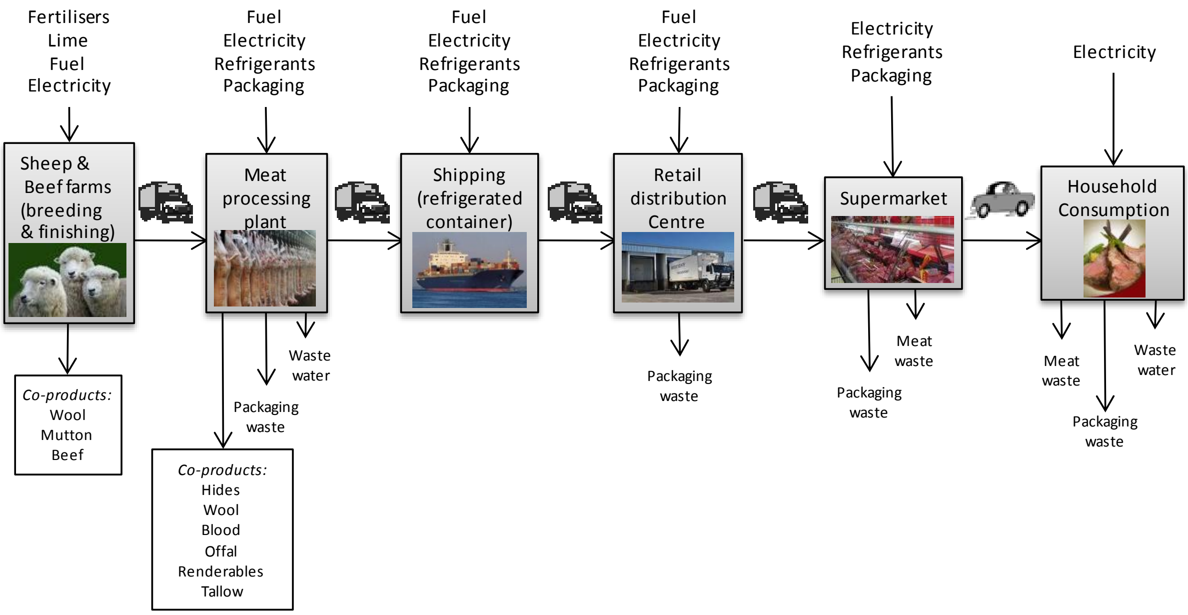


**Figure 1**: Representation of the various stages in the Life Cycle Assessment (LCA) of lamb showing the main resource inputs, outputs and co-products.

While LCA has been widely used in engineering for designing products based on resource efficiency its use has expanded to include agricultural products during the last decade. It has ISO standards developed for its application (ISO14040 series) and is used to examine a range of different resource use and environmental emission impact categories (e.g. resource depletion, climate change, acidification, eutrophication, eco-toxicity). An advantage of evaluating multiple environmental impact categories is that any 'pollution swapping' can be identified when new product or system production options are being examined e.g. reducing one impact may result in an increase other impacts. Despite the latter advantage, the use of LCA in agriculture during the past decade has had a strong singular focus on climate change and its use for estimating the carbon footprint of products, i.e., the total greenhouse gas (GHG) emissions throughout a product's life cycle. However, with the concerns about energy resources, fresh-water availability and water quality deterioration, there has been a recent interest in using LCA in research on these other key resource issues.

This paper covers two main areas and the role of LCA in each one. The first examines market demands and opportunities from a range of different stakeholder perspectives and presents results from some New Zealand (NZ) agricultural product studies using LCA. The second area focuses on enhancing on-farm efficiency and considers variability between farms, the importance of having a whole farm system focus and the contribution from fertilisers.

## Market demands and opportunities

### *The power of large supermarket chains*

In the United Kingdom (UK), Tesco's (the fourth largest retailer globally on a revenue basis) led a process to provide consumers with information about the GHG emissions associated with their products using eco-labelling. Their chief executive Sir Terry Leahy promised "a revolution in green consumption" in 2007 when carbon footprint labelling was introduced and they currently have about 120 products labelled and over 500 assessed. However, they recently announced that they were going to stop their labelling programme due to the cost and time requirements and because it was not being taken up by other supermarkets.

Other UK supermarkets have taken a different approach. For example, Marks&Spencer have decided against carbon labelling but have defined requirement for their main suppliers to provide information on the carbon footprint of their products over the stages of the life cycle where they have control AND to have a plan in place to reduce carbon emissions over time.

Walmart, the world's largest retailer, is working on a simple sustainability product index based on a life cycle approach. They are requiring suppliers to provide information on GHG emissions, waste generation and water use as part of the process in developing this index.

In France, the government announced plans for mandatory labelling of all goods in supermarkets and they are currently in a one-year trial period with a limited range of products in some supermarket chains. An example of this is given in Figure 2 for one supermarket chain, which covers the three indicators of GHG emissions, water quality (Eutrophication Potential) and biodiversity. The NZ lamb product in this example was in the highest (worst) category rating for all three indicators. There are concerns about the methodology being used, particularly for biodiversity which is based on the very crude indicator of the area of land used to produce one kg of product! It makes no recognition of important aspects such as flora and fauna diversity in pasture systems and integration of trees on farms. The NZ government and meat industry are currently working with the supermarkets on these concerns.

| | Gigot d'agneau ... (14608) | | |
|---|---|---|---|
| | RECHAUFFEMENT CLIMATIQUE | POLLUTION AQUATIQUE | BIODIVERSITE |
| Note | kg éq. CO2 | kg éq. P (E-06)* | m²année |
| A | <0,16 | <26 | <0,15 |
| B | entre 0,16 et 0,33 | entre 26 et 51 | entre 0,15 et 0,29 |
| C | entre 0,33 et 0,49 | entre 51 et 77 | entre 0,29 et 0,44 |
| D | entre 0,49 et 0,65 | entre 77 et 102 | entre 0,44 et 0,59 |
| E | entre 0,65 et 0,82 | entre 102 et 128 | entre 0,59 et 0,74 |
| F | entre 0,82 et 0,98 | entre 128 et 153 | entre 0,74 et 0,88 |
| G | 1,33 | 235 | 1,63 |

Impact croissant

**Figure 2:** An example of environmental details for a NZ lamb cut from one of the supermarkets in the French national eco-labelling trial. It covers three indicators relating to (from left to right) GHG emissions, water quality and biodiversity and categorises them from low to high (A to G) impact.

***Implications at a national level***

Many countries have developed national policy relating to environmental quality and some have set national targets for future reductions. One example is the signatories to the Kyoto Protocol and commitments to reduction in GHG emissions. The UK set a large reduction target for GHG emissions and a recent study (Williams et al., 2011) examined the potential for the UK to achieve a 70% decrease by 2050. The comprehensive study highlighted the significant 30% total contribution from food as well as other contributors such as transportation. It concluded that large GHG emission reductions could only be achieved with a mix of options, many of which would have a significant effect on the public. Several of the factors with the largest potential for reduction were; cutting fossil fuel use ("decarbonising" energy), increasing efficiency of food production and dietary changes. For the latter, the largest potential for emissions reduction identified was a change to no meat diets. It is unknown whether such reviews could eventually be used for developing national policy to achieve the desired target for GHG reduction. Nevertheless, they do highlight the vulnerability of our meat producing sectors to possible regulatory guidelines on food consumption issues and on the implications of eco-labelling as discussed in the previous section.

***Proactive producers***

There are now some major international companies that are taking a proactive approach to increasing the environmental efficiency of their products throughout the life cycle. A leader in this area is Unilever, who is a major international consumer goods company. They have been using LCA as a tool in determining "hot-spots" of resource use and environmental emissions associated with their goods, recognising the need to evaluate and account for all stages of a product's life cycle. This has progressed to using life cycle management where they use an integrated approach to continuously improve resource and environmental efficiency in areas such as sourcing raw materials, manufacturing methods, designing packaging and minimising waste (Unilever, 2012).

In NZ, Fonterra also has a strong focus on energy efficiency and waste reduction throughout their processing plants. They have been actively involved in research in NZ on carbon footprinting , which has resulted in them being one of the world leaders in working with other large international milk processors (e.g. Arla and Danone) and LCA researchers to develop a common methodology for carbon footprinting of milk through the International Dairy Federation (IDF, 2010). It was seen as critical to work towards a common methodology to ensure greater comparability of estimates of the carbon footprint produced by different groups and countries and for credibility in work on achieving a reduced carbon footprint over time.

A similar approach towards developing a common methodology for lamb carbon footprinting has commenced via the International Meat Secretariat, with Beef+LambNZ having a lead role in the process. This involves lamb producers in many countries throughout the world in conjunction with LCA researchers that have been actively involved in the sector.

***New Zealand carbon and water footprinting studies***

During the last five years, there have been a range of MAF and industry funded projects examining the carbon footprint of exported products using an LCA approach. The genesis of the projects was the potential concern by markets about the contribution from transporting our products to distant overseas markets, the increasing demand by major supermarket chains for carbon footprint information on NZ products and the need for identification of opportunities for carbon footprint reduction.

A lamb carbon footprint study covered the production and processing of the NZ-average lamb that was exported by ship to the UK, cooked and consumed by a UK household and including waste (uneaten lamb and sewage) stages (Ledgard et al., 2010b). The carbon footprint averaged 19 kg $CO_2$-equivalents/kg lamb meat, with 80% from the cradle-to-farm-gate (mainly animal methane and nitrous oxide ($N_2O$) emissions), 3% from processing, 5% from all transportation stages (predominantly from shipping), and 12% from retailer/consumer/waste stages (dominated by retail storage and home cooking) (Figure 3).

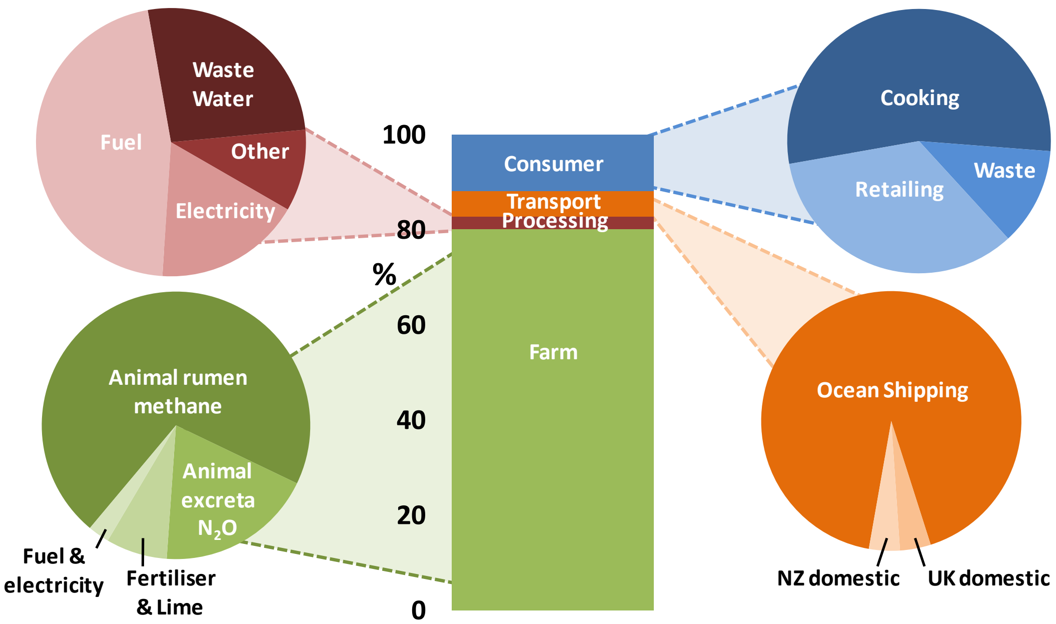


**Figure 3**: Relative contribution from the main life cycle stages to the carbon footprint of NZ lamb consumed in the UK (Ledgard et al., 2010b).

The lamb study indicated that shipping from NZ to the UK contributed only 4% of the total carbon footprint and the NZ milk carbon footprint study (Ledgard et al., 2009) similarly showed that shipping averaged only 5% of the carbon footprint from the cradle-to-overseas-port stages. In contrast, the kiwifruit carbon footprint study (Mithraratne et al., 2010) showed that shipping was the dominant contributor to the total carbon footprint at about 40%, with the orchard stage being a relatively small component (about 15-20%).

All carbon footprint studies with products produced from the pastoral sectors (milk, meat, fibre) have shown dominance of the cradle-to-farm-gate stage, at about 70-90% of the total carbon footprint, and this was largely due to animal-related methane and nitrous oxide emissions (e.g. Figure 3). Such studies have yet to extend to other LCA impact categories but it is likely that the farm stage will be a much smaller contributor to total energy or fossil fuel use but an even larger contributor to Eutrophication Potential.

In NZ, there is currently a strong research focus on water footprinting. Water has long been recognised as a key resource for agricultural production with livestock farming using approximately 70% of the global water withdrawals (FAO, 2006). However, the implications of water abstraction for agriculture vary markedly on a spatial basis, depending on ground and surface water resources and on the level of replenishment by rainfall. Thus, while climate change (associated with GHG emissions and carbon footprinting) is a global issue, water consumption and water quality deterioration are local issues.

A range of methods have been and are being developed in this relatively new research area of water footprinting, with each varying in the way in which they account for water consumption and impacts (e.g. Milà i Canals et al., 2009; Ridoutt and Pfister, 2010; Hoekstra et al., 2011). Most attention has been given to the total water footprint calculation method of the Water Footprint Network (WFN) and this has resulted in typical world average estimates of 1,054 litres water/litre milk and 10,943 litres water per kg beef meat (Mekonnen and Hoekstra, 2010). These figures consist of blue, green, and grey water. The blue water footprint is the volume of groundwater and surface water consumed, i.e., withdrawn and then evaporated or incorporated in the product. The green water footprint is the volume of water evaporated from soil and transpired by plants in the production system as well as that incorporated into the product. The grey water footprint is the volume of fresh-water that would be required to assimilate or dilute the load of pollutants based on existing ambient water quality standards (Hoekstra et al., 2011).The main contributor to such high volumetric water numbers calculated by the WFN is green water. A number of researchers have indicated that green water should either not be included in the calculations or should only be included as a change from a previous natural reference land use system. Similarly, there is disagreement about whether grey water should be included and in LCA research, water quality deterioration due to eutrophying pollutants is already accounted for within the Eutrophication Potential indicator. The water footprint methodology is evolving and the pending release of an ISO methodology (ISO 14046) on water footprinting is likely to direct future water footprint assessments.

A study by Zonderland-Thomassen and Ledgard (2012) resulted in total water footprint estimates of 945 litre $H_2O$/kg fat-and-protein-corrected-milk (FPCM) for a rain-fed Waikato dairy farm of which most (72%) was from green water, with grey water at 28% and blue water at only 0.1% (Figure 4). The total water footprint of an irrigated Canterbury dairy farm was 1084 litre $H_2O$/kg FPCM, of which most (46%) was from green water, with blue water at 23% and grey water at 31%.

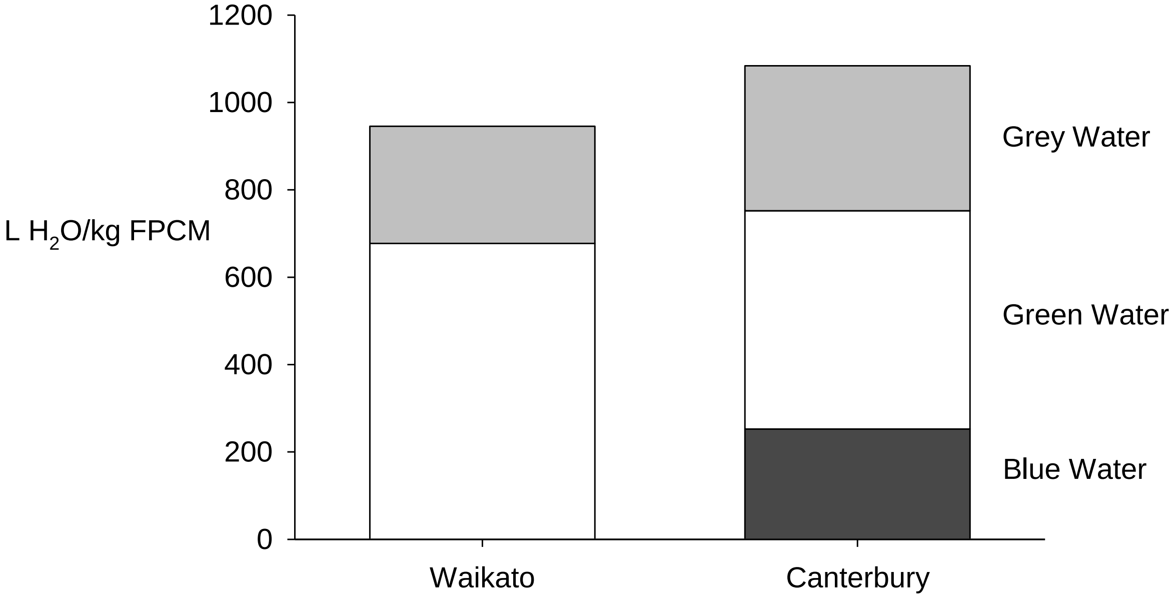


**Figure 4:** Blue, green, and grey water footprint of average dairy farm systems in the Waikato and Canterbury regions of NZ (Zonderland-Thomassen and Ledgard, 2012).

In the limited number of recent studies on pastoral agricultural systems, most focus has been on blue water. The environmental impact of blue water can be assessed by using specific characterisation factors. In contrast to carbon footprinting which is a global issue, water footprinting needs to account for the implications at a regional or catchment level. Thus, researchers have been developing indices to account for the availability or scarcity of water at a spatial scale. This has resulted in one group (Pfister et al., 2009) developing a Water Stress Index (WSI) and have produced a global map of values. NZ has a relatively low overall WSI with an average of 0.012 compared to the global average of 0.602, although there is variation within NZ with Canterbury having a relatively higher value of 0.017 and Waikato at 0.0106. Application of this index resulted in values for the Waikato and Canterbury-irrigated farms of 0.01 and 7.8 L $H_2O$-equivalent/kg FPCM, respectively. These water footprint indicators that account for regional water scarcity have more meaning for end-users than volumetric estimates. For farming systems, these indicators should be complemented by indicators which assess depletion of water resources, as well as indicators which assess water degradation impacts to ecosystems and human health while avoiding double-counting.

**Enhancing on-farm efficiency**

LCA is a useful tool to determine where hot-spots are at stages throughout and within the life cycle. For pastoral agriculture, at the cradle-to-farm-gate stage of the life cycle the main contributors to GHG emissions and the N-emissions component of Eutrophication Potential is the grazing animal and the amount of feed consumed and excreta returned to land (e.g. see Figure 3). In contrast, for total energy or fossil fuel use, the collection and feeding of animals is a minor contributor, with the main one being the fertilisers used on farm (Ledgard et al., 2011a).

***Variability between farms***
In a recent study for Fonterra and MAF, variability in the carbon footprint between farms was examined and it showed a nearly two-fold range with a normal shaped distribution (e.g. see Figure 5 for the Waikato region; Ledgard et al., 2011b). Correlation analysis with a wide range of farm and site factors revealed that the strongest relationship was with milksolids production per cow (relatively more emissions go to product and less to cow maintenance, thereby increasing efficiency per kg milk produced) (Figure 6). The second main factor was cow replacement rate (less emissions to grow replacement animals means a lower contribution from non-productive animals; data not shown). This highlights the potential for changing farm management practices to reduce the farm carbon footprint. Interestingly, a decreasing carbon footprint was significantly correlated in all regions with increasing profitability or Economic Farm Surplus (Figure 6). This is likely to be associated with the main factors described above reflecting feed conversion efficiency (i.e. feed intake per kg milk produced being lower with increased milksolids/cow and reduced replacement rate).

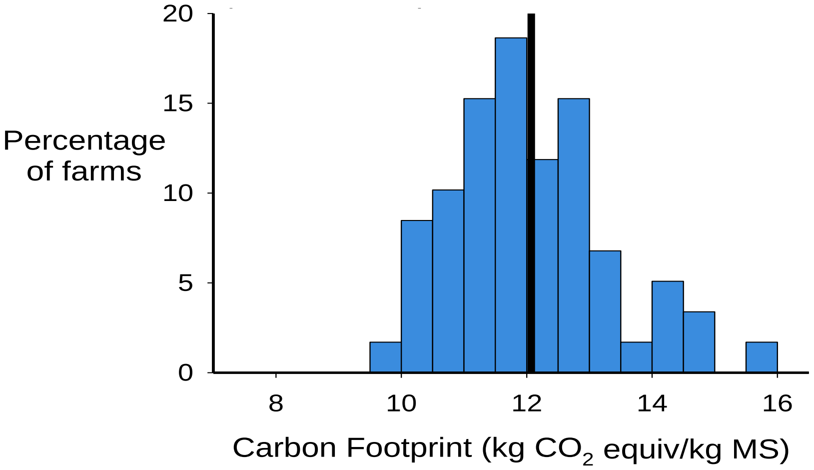


**Figure 5:** Variability in carbon footprint (cradle-to-farm-gate) of milk produced from individual farms in the Waikato region, based on survey data from farms in the DairyNZ DairyBase (from Ledgard et al., 2011b).

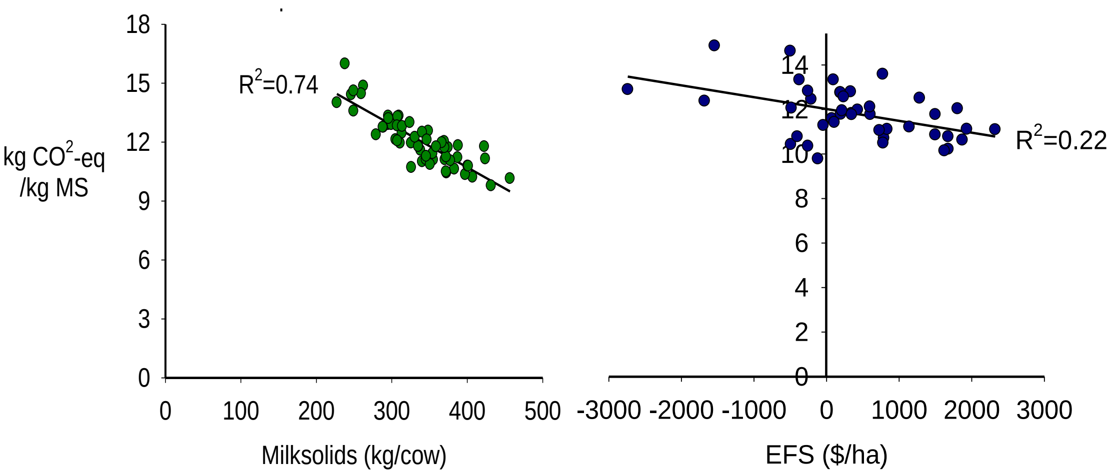


**Figure 6:** Relationship between the carbon footprint of milk on individual Waikato dairy farms and milksolids production per cow or Economic Farm Surplus (EFS) (from Ledgard et al., 2011b). Both correlation coefficients were statistically significant ($P<0.05$).

Measurements in the Lake Rotorua catchment with a group of dairy farms also showed increased profitability with decreased carbon footprint. This was correlated with decreased N leaching (Ledgard et al., 2010a) reflecting some common drivers to both environmental effects and the potential for synergies in reducing multiple environmental emissions.

***Importance of a whole farm system focus***

Intensification of agriculture is ongoing and in the NZ dairy sector this is associated with increased use of brought-in supplementary feed. Some of the implications of this were examined in a DairyNZ farmlet trial that included comparison of a base farm system with one that brought in 5 t DM/ha/year of maize silage and increased the stocking rate and milk production on farm by about 30% (Jensen et al., 2002). The effects of these two farmlets on energy use, N leaching and GHG (methane and $N_2O$ according to the NZ GHG inventory) emissions at the dairy farm level only indicated an increase in efficiency (i.e. resource use or emissions per kg milk) with maize silage integration (Figure 7a). For the proposed NZ Emissions Trading Scheme (with agriculture to be included from 2015 onwards), which will use emissions intensity at the dairy farm level only, this would be associated with a reduction in GHG costs per kg milk. A key reason for the benefit from reduced N leaching and $N_2O$ emissions is the low protein content of maize silage resulting in low N excretion and loss from animals per kg DM consumed and per kg milk produced.

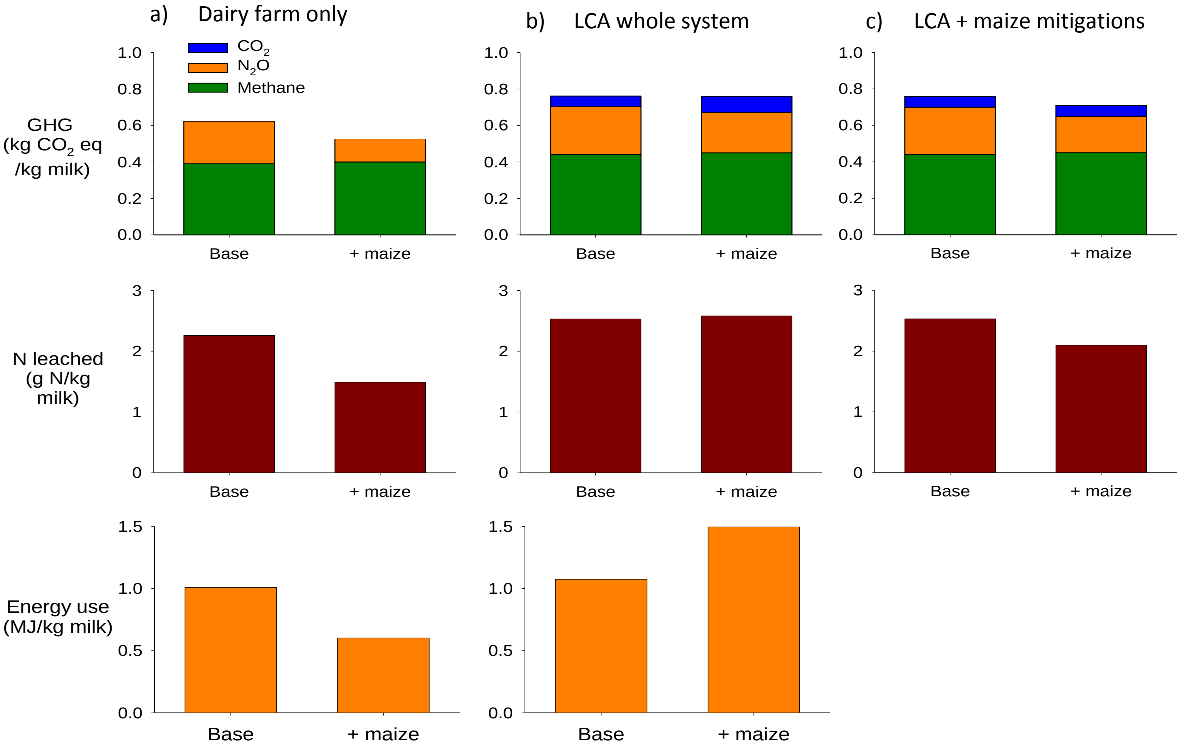


**Figure 7:** Results from analyses of the DairyNZ RED trial base and +maize (+5 t maize silage DM/ha/year and 30% increase in stocking rate) farmlets (Jensen et al., 2002) for GHG emissions, N leaching and energy use. Data refers to a) the dairy farm (or milking platform) only and for GHGs it excludes $CO_2$ emissions (i.e. equivalent to NZ Inventory agricultural emissions), b) LCA-based whole system analyses (including all off-farm related emissions and energy use), and c) the same as for b except that the maize area was assumed to use nil cultivation and low N fertiliser use based on soil N testing. (Energy data for c was unavailable).

However, if a whole farm system LCA-based approach is taken, the relativity between treatments changes as the resource use and emissions associated with all the inputs and the maize silage production (off-farm) and use are included (Figure 7b). Energy use per kg milk is about 40% higher when the fuel use for maize crop establishment, harvesting, cartage and feeding are accounted for, as well as energy use from various inputs such as fertilisers. Nitrogen leaching and GHG emissions per kg milk are slightly higher for the maize-supplemented farmlet system when the effects of N fertiliser use on maize and N leaching from maize are included in the calculations. For GHG emissions, the reduction in $N_2O$ emissions is being countered by the increase in $CO_2$ emissions. Additional analysis of the systems indicated that integration of mitigation practices in maize production (nil cultivation and reduced N fertiliser use based on use of soil N testing) had potential to reduce N and GHG emissions intensity per kg milk and be lower than the base farmlet system (Figure 7c). This study highlights the importance of taking a life cycle approach to account for the total resource use and environmental emissions of agricultural products.

***Fertiliser contributions***

Fertilisers represent the most expensive input on most NZ pastoral farms and are a major component of the total non-renewable resource use on farm. A NZ study on the LCA of fertilisers revealed a high energy use associated with natural gas use for urea manufacturing and fuel use in transporting raw materials (e.g. phosphate rock, sulphur and potash) or processed fertilisers (Ledgard et al., 2011a). That study showed that approximately 77% of the total energy use for the average NZ dairy farm (cradle-to-farm-gate stage) was associated with fertilisers. For GHG emissions on-farm, fertilisers are the main contributor after that of animal methane and $N_2O$ emissions, at approximately 12% of total emissions for the average NZ dairy farm or 5% for the average sheep and beef farm (Figure 3).

Eutrophication of waterways is an important environmental issue in NZ and fertilisers have a contributing role. However, impacts of fertilisers on waterways are often estimated in a very simplistic way. This is particularly evident in Figure 2, where lamb has been attributed a high Eutrophication Potential which was probably based on a simplistic calculation assuming that a fixed percentage of N and P applied in fertilisers is lost to waterways. In NZ, a huge research effort over time has resulted in fertiliser recommendations to farmers on the most appropriate rate and timing of application using nutrient budgeting for optimising plant use and minimising direct loss to waterways. For example, for N fertiliser, the use of low application rates and a small component of the NZ total applied in winter means that direct N leaching of fertiliser-N is < 1% of that applied (e.g. Ledgard et al., 1998). Thus, it is important that models that attempt to account for Eutrophication Potential are based on field research where actual N and P losses have been measured (e.g. the P loss model in the OVERSEER® nutrient budget model; McDowell et al., 2005) and that they account for all contributors to eutrophication.

Fertilisers provide a good example of the importance of an LCA approach to defining environmental efficiency of agricultural products. They are a key input that has potential off-farm and on-farm impacts but their use is critical for profitable farming. The major research and extension effort in NZ on efficient and optimum use of fertilisers has multiple economic and environmental benefits, with synergies for reducing total resource use and environmental emissions.

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