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Life cycle assessment – a tool for evaluating resource and environmental efficiency of agricultural products and systems from pasture to plate

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ABSTRACT

Life cycle assessment is a useful tool to evaluate the resource use and environmental efficiency of agricultural systems and products, and to account for these along the whole supply chain or life cycle. Its application to agricultural products is most evident with carbon footprinting, where it is being used at industry, policy and consumer levels including for eco-labelling. Research in dairy, sheep and beef systems has shown that the farm-related stage is the main contributor to product carbon footprints and that in New Zealand they have been gradually reducing over time with increasing productivity. While the carbon footprints of New Zealand pastoral agricultural products are generally low compared to overseas products, there can be up to a two-fold variation between individual farms, illustrating the potential for on-farm efficiency gains. Fossil fuel and total energy use on New Zealand farms are low compared to overseas but are increasing with greater use of high energy-demanding nitrogen fertiliser. Water footprinting is likely to become an important resource indicator with the global focus on fresh-water scarcity. A key benefit of life cycle assessment is that it enables evaluation of the potential impacts of products on multiple resource use and environmental indicators for system optimisation.

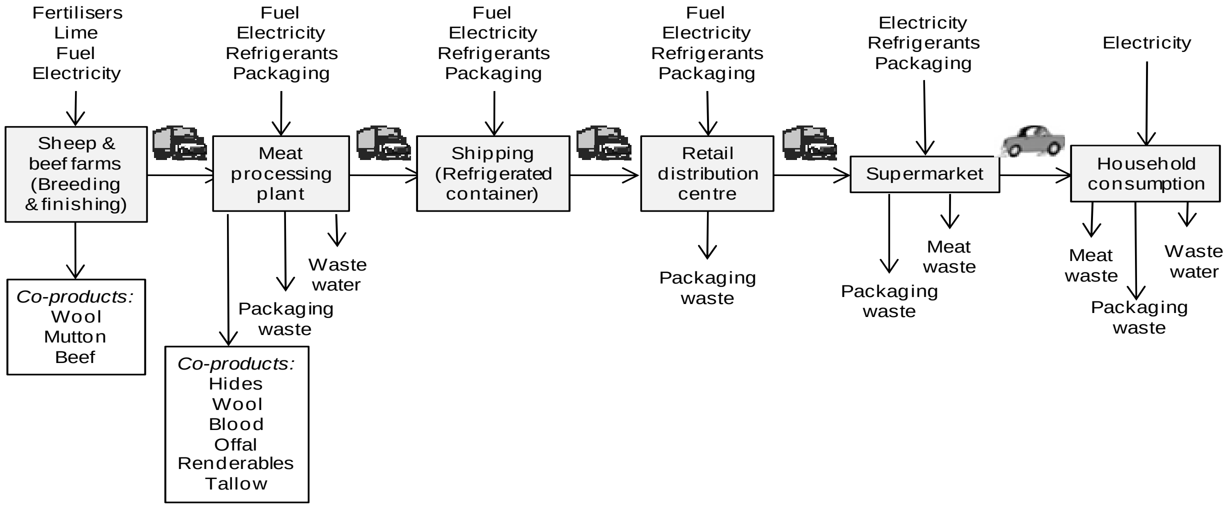
Keywords: carbon footprint; energy use; fossil fuels; water footprint.

INTRODUCTION

Overseas supermarkets, consumers and New Zealand (NZ) policy bodies are requesting information from agricultural producers on their use of basic resources, namely energy, water and nutrients, and their environmental impacts. This puts a focus on environmental efficiency. Similarly, at the agricultural production system level there is a need for increasing the efficiency of resource use to improve farm profitability and competitiveness of product supply.

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.

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 in designing products for resource efficiency its use has expanded to include agricultural products during the last decade. It has ISO standards developed for its application (British Standards Institution, 2006; 2008) and is used to examine a range of different resource use and environmental emission impact categories such as 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. For example, reducing one impact may result in an increase in 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, that is the total greenhouse gas (GHG) emissions throughout a product's life cycle. However, with the concerns about energy resources and fresh-water availability, there has been a recent interest in using LCA in research on these two key resources. This paper describes research on carbon footprinting, energy use and water footprinting in NZ pastoral agriculture, including case studies in the dairy and red meat sectors and opportunities for efficiency gains.

CARBON FOOTPRINTING

International drivers

Concern about globalisation of food flows and the environmental implications led to the term "food-miles" in the 1990s (Paxton, 1994). This simple indicator generally refers to the energy requirement and associated GHG emissions from the main transportation stage in delivering a product to a market. Since NZ is a major exporter of agricultural products and Europe is an important market, the long distance for product transportation represents a potential threat due to consumer bias against NZ products. Fortunately, however, the flaw in this limited concept has been highlighted and attention shifted to the carbon footprint of a product. The push for information on the carbon footprint of products was initially driven by large supermarket chains in the United Kingdom (UK). This led to trialling of carbon labelling of a range of product types by Tescos in their supermarkets. Other have also been active in this area, including Marks and Spencer (2011) who aim to minimise their own carbon footprint and more importantly to ensure that their suppliers have programmes to reduce the carbon footprint of their products over time. This has spread to a wide range of other countries, with France and South Korea proposing mandatory labelling of all products in supermarkets.

Potentially, producers wanting to supply agricultural products to major supermarkets in the UK and some other countries would be required to provide estimates of their carbon footprint and plans for reducing them. In this way customers could compare the GHG efficiency of different products and use this as selection criteria. The significance of the carbon footprint of agricultural products was highlighted in the FAO (2006) report on "livestock's long shadow", which noted that 18% of global GHG emissions were from livestock and that this exceeded emissions for global transport.

New Zealand commitments

The NZ government has ratified the Kyoto Protocol and has indicated, by setting up and passing emissions trading legislation, the Emission Trading Scheme (ETS), whereby all sectors of the economy will have to limit GHG emissions below agreed targets or to take financial responsibility for excess emissions. Current policy is that the agricultural sector will have to participate in this process from 2015 onwards and is expected to be taking action by 2012 (Ministry for the Environment, 2011).

The ETS means that NZ agriculture can potentially benefit from the implementation of practices that reduce total GHG emissions or increase efficiency in terms of the GHG emissions per kg of product. In order to foster progress in the overall area, the government has increased support for research and interaction with the agricultural industry in a range of areas including development and extension of mitigation practices to reduce GHG emissions, and support for industry-led projects evaluating the carbon footprint of a range of agricultural products.

Carbon footprinting methodology

A carbon footprint analysis accounts for the resources consumed and the GHG emissions at all stages of the life cycle of the product studied. These range from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product, to its reuse, and recycling or final disposal (Guinée *et al*., 2002). In LCA, the global warming potential (GWP) indicator is used and results are expressed in the common unit of carbon dioxide (CO_2)-equivalents (CO_2-e). The GWP represents the heat absorption capacity of the individual gases (methane (CH_4), nitrous oxide (N_2O), CO_2 and some fluorocarbons and sulphur hexafluoride) relative to CO_2 over a 100 year reference time horizon (Ramaswamy *et al*., 2001). Carbon footprinting methods based on LCA utilise a number of internationally-recognised ISO standards (British Standards Institution, 2006), databases such as Ecoinvent (Frischknecht *et al*., 2005) and software tools such as GaBi, and

Simapro. One important aspect of carbon footprinting aligned to ISO standards is the allocation of total GHG emissions from a system between co-products where there is more than one product from a system process (Figure 1).

For pastoral agriculture, the significant emissions of CH_4 and N_2O need to be accounted for and aligned to internationally-accepted methodologies. New Zealand's commitment to the Kyoto Protocol requires it to report national emissions annually using methodology reviewed and accepted by the Intergovernmental Panel on Climate Change (IPCC). This includes calculation of agricultural CH_4 and N_2O emissions using emission factors based on NZ-specific research (Ministry for the Environment, 2007). The methods used in calculating agricultural CH_4 and N_2O emissions for the NZ GHG Inventory have generally been integrated into NZ carbon footprinting tools such as within the OVERSEER® model (Wheeler *et al.*, 2011).

Carbon footprint of New Zealand dairying

A Fonterra-led project examined the carbon footprint of a range of dairy products covering the average NZ dairy farm system, all milk processing plants, and transportation stages including shipping to the overseas ports of a wide range of their markets, a "cradle-to-overseas-port" stages of the life cycle (S.F. Ledgard, Unpublished data). This study showed that the relative contributions to the carbon footprint were 85% for the cradle-to-farm-gate stage, 10% for processing and 5% for all transportation. This reinforced the relatively small contribution that shipping to overseas markets makes to the carbon footprint of NZ dairy products.

Emissions of GHGs from the cradle-to-farm-gate stage were 940 g CO_2-e per litre milk, with 59% as CH_4 (largely from enteric rumen fermentation), 24% as N_2O (with ¾ from animal excreta and ¼ from nitrogen (N) fertiliser) and 17% as CO_2. The latter comprised 34% from N fertiliser (mainly associated with manufacturing), 12% from non-N fertilisers (mainly from transportation of raw materials), 5% from lime (mainly from CO_2 release after reaction in soil), 7% from fuel use, and 8% from electricity use. A third of calculated CO_2 emissions were from CO_2 release from soil associated with land use change such as conversion of forestry land into dairying. The farm system calculations in the cradle-to-farm-gate stage, covered all components of the production system including GHG emissions from land used to produce feed imported onto the farm, land used to graze dairy replacements and for wintering dairy cows.

Although this study was based on an average NZ dairy farm system, there is a wide range in carbon footprint values between individual farms. This was evident in a study of farms in the Rotorua area (S.F. Ledgard, Unpublished data), which showed a two-fold variation of 0.9-1.8 kg CO_2-e/litre milk associated with differences in production systems and management practices.

Carbon footprint of New Zealand sheep and beef

Recent studies have resulted in the first carbon footprint of lamb throughout the whole life cycle (S.F. Ledgard, Unpublished data). It covered the production and processing of NZ lamb that was exported by ship to the UK, cooked and consumed by a UK household and including waste of uneaten lamb and sewage stages. The carbon footprint averaged 19 kg CO_2-e/kg lamb meat, with 80% from the cradle-to-farm-gate (mainly animal CH_4 and 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 2).

The study excluded the customer travel to purchase the lamb, in order to comply with the recognised UK carbon footprint methodology (British Standards Institution, 2008). However, its contribution was examined in a sensitivity analysis and its inclusion added up to 7% to the total carbon footprint depending on the mode of transport and

FIGURE 2: Relative contribution from the main life cycle stages to the carbon footprint of New Zealand lamb consumed in the United Kingdom (Ledgard *et al.*, 2010b).

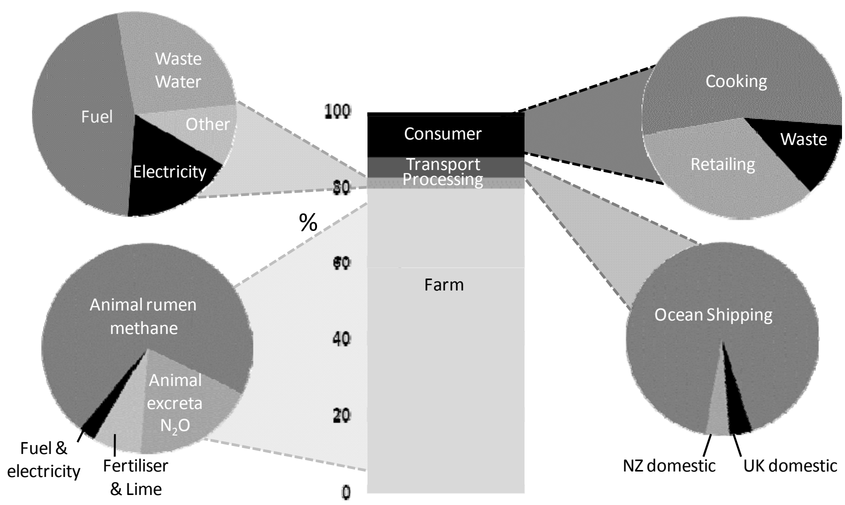
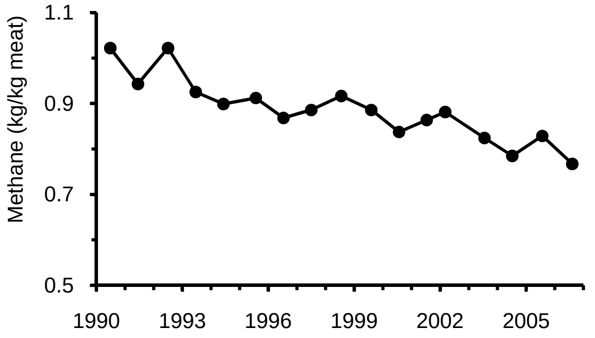


FIGURE 3: Methane emissions from New Zealand-average sheep meat calculated using Beef and Lamb New Zealand (Beef and Lamb New Zealand, 2010) data and the New Zealand greenhouse gas inventory methodology.

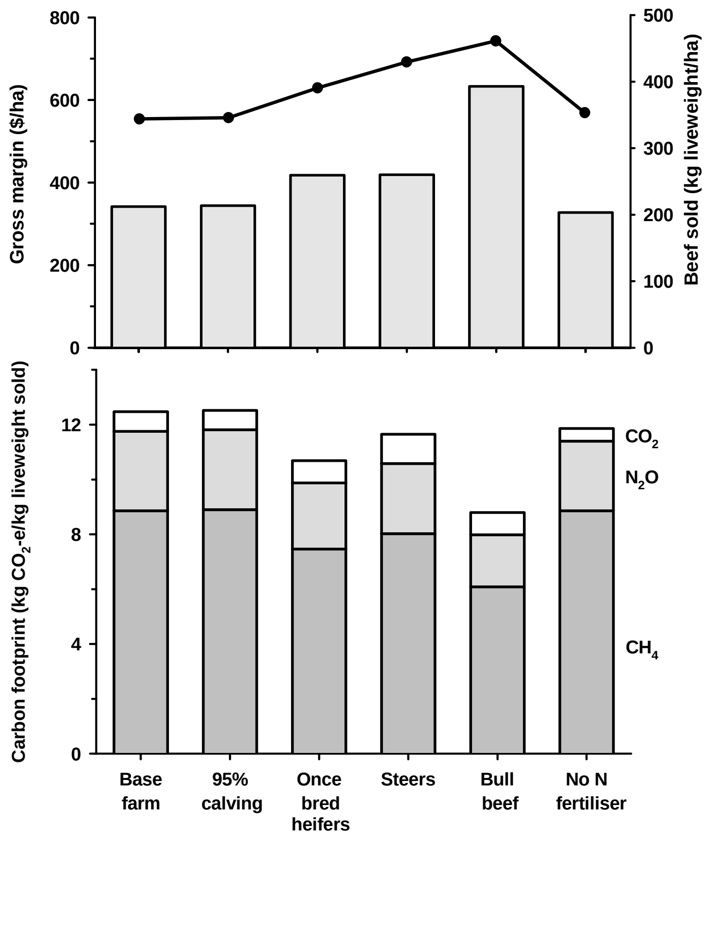


food purchasing practices. The method of cooking by the consumer was also important with cooking-related emissions being 20% higher by roasting the lamb compared to frying it. Thus, the consumer can have a significant effect on the carbon footprint of agricultural products.

The on-farm stage was the main contributor to the carbon footprint. This was predominantly from animal-related CH_4 and N_2O emissions comprising 72% of the total carbon footprint. Thus, the largest opportunity to reduce GHG emissions on-farm is to increase the efficiency of feed conversion into lamb meat. This has been occurring steadily over time as is evident from the reduction in CH_4 emissions per kg sheep meat produced in NZ (Figure 3). The main reasons for this are due to an increase in the lambing percentage of ewes, increased growth rate of lambs and finishing lambs at heavier weights. Consequently, NZ sheep farms produced slightly more lamb meat by weight in 2009 compared to 1990, but from a 43 percent smaller national flock (Beef and Lamb New Zealand, 2010). This has been estimated to coincide with a reduction in carbon footprint by approximately 22%. In practice, the main driver of these reductions in GHG emissions is increased farm profitability through increased on-farm efficiency.

A study on the carbon footprint of NZ beef has recently been completed (M. Lieffering, Unpublished data). This also showed the predominance of the on-farm component and identified differences between beef sources, with beef derived from the dairy sector having a lower carbon footprint. The latter was due to beef calves derived from the dairy sector being a by-product and having minimal allocated GHG emissions compared to traditional beef breeding systems where all the GHG emissions associated with breeding animals contribute to the carbon footprint of the beef sold for processing. An example of the effect of this and of some farm practices on the carbon footprint per kg beef expressed per unit of live weight, is shown in Figure 4 based on scenario analyses for a Landcorp case study farm. The largest calculated reduction in carbon footprint of 30% was from switching from a beef breeding system to one based on bull calves sourced from the dairy industry and running them as bull beef. The difference in effectiveness between the bull beef and steer systems, where both are assumed to be derived from the dairy sector, was influenced largely by the period to final finishing weight. This was up to 28 months for bull beef and up to 40 months for steers. An intermediate level of carbon footprint reduction of 14% was calculated for the once-bred heifer system based on buying in weaner Hereford/Friesian heifers derived from the dairy sector. These bull beef, steer and once-bred

FIGURE 4: Modelled analyses of changes in beef farm system on a Landcorp case study farm on gross margin and live-weight sold (modelled using Farmax) and on the carbon footprint for beef for the cradle-to-farm-gate stage (Lieffering *et al.*, 2010). In the top graph the line refers to gross margin and the bars to beef sold.



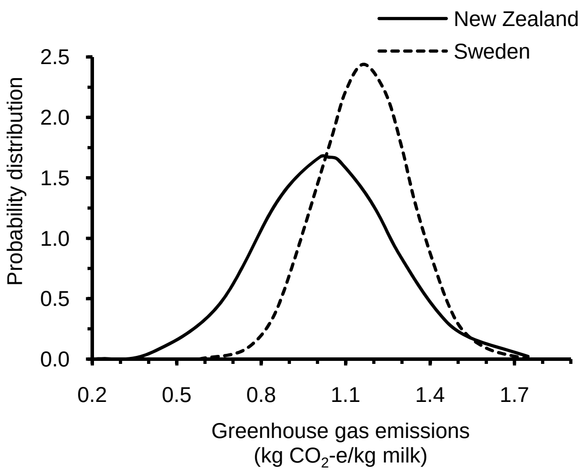
heifer systems were all estimated to achieve higher beef production per hectare and higher profitability using Farmax modeling (Webby and Bywater, 2007) (Figure 4). Management practices of increasing calving % from 90% to 95%, or reducing use of N fertiliser from 30 kg N/ha/year to 0 kg N/ha/year, were calculated to have little effect on the carbon footprint.

Comparison with other published carbon footprint studies and wider implications

There have been a range of international published studies on pastoral farming systems covering the farm-stage only, or cradle-to-farm-gate. However, it is difficult to make a direct comparison between them and the NZ studies because of differences in methodology used. Thus, valid comparison is generally only possible where comparative studies have been made using the same methods. There have been few such studies.

Recent research comparing average NZ and Swedish dairy farm systems, using the same methodology, indicated that the average NZ dairy farm had a 14% lower carbon footprint (Figure 5; Flysjö *et al*., 2011) but that there was a relatively wide spread around these calculated average values when uncertainty analysis was applied. The NZ dairy system had much lower emissions associated with feed production since it is based on outdoor grazing of perennial pastures, whereas the Swedish dairy system involves a significant component of housing, cut-and-carry feeding and large amounts of imported feeds. However, the Swedish system had lower CH_4 emissions per kg of milk because of the much higher milk production per cow. The net effect of these and other differences in system and management practices was a relatively small advantage to the NZ average dairy farm system. However, as noted earlier, there is up to a two-fold variation in carbon footprint between individual farms within NZ dairy farms (S.F. Ledgard, Unpublished data). This is much greater than the difference between the average NZ and Swedish dairy systems.

FIGURE 5: Greenhouse gas emissions from average New Zealand and Swedish farm systems shown as frequency distributions to reflect variability in calculation parameters (Flysjö *et al*., 2011).



The only other published comparative LCA study that included NZ farming systems was that of Williams *et al*. (2008). They applied generic models of production systems and used surveyed sheep production data, based on Beef and Lamb New Zealand information (then Meat and Wool New Zealand) to calculate a weighted average carbon footprint for lamb production in NZ and UK. Their comparative study covered the farm system, meat processing and transportation stages, including shipping from NZ, to a UK retail distribution centre. The estimated GHG emissions for lambs produced in the UK and NZ were 14.1 and 11.6 kg CO_2-e/kg lamb product, respectively. Thus, even when shipping was included the NZ production system had a lower carbon footprint and they attributed this to several factors including greater use of N fertiliser in the UK and greater allocation of total sheep system GHG emissions to wool in NZ where wool is a more valuable co-product from sheep production than in the UK.

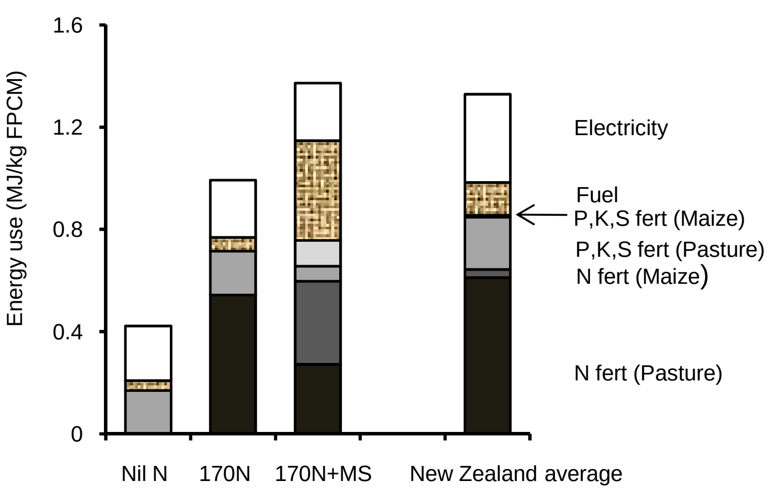
There have been no carbon footprint studies directly comparing sheep and beef. While there have only been a few lamb studies, there have been many more published studies on the carbon footprint of beef. For the cradle to-farm-gate stage, most beef studies are within the range of 7-19 kg CO_2-e /kg live weight (LW), with results influenced greatly by methodological differences as well as by farm system differences. The study of Williams *et al*. (2008) included evaluation of the carbon footprint for UK beef and for UK lamb based on generic models that accounted for the range of farm systems that exist. Their estimate for GHG emissions per kg LW for the cradle to-farm-gate stage for average UK lamb was only 57% of that for the average UK beef. Similarly, our recent carbon footprint studies also resulted in lower carbon footprint values for average NZ lamb than for NZ beef, averaged over the traditional breeding and bull beef systems, at 8.6 and 10.5 kg CO_2-e/kg LW, respectively. This lower carbon footprint for lamb can be attributed to higher fecundity in sheep of approximately 125% lambing by ewes compared to 95% calving by breeding cows, higher average growth rates in lambs and wool as a significant co-product from sheep. However, it must also be recognised that a significant component of NZ beef is from cull dairy cows which have a low carbon footprint of about half that of the average for traditional beef. In NZ its inclusion brings the weighted average carbon footprint for beef at the farm-gate down to a similar value as that for lamb. This further highlights the importance of accounting for whole production systems and co-products when carrying out a carbon footprint analysis.

Some generic studies have made estimates of the carbon footprint per kg meat comparing a number of red and white meats (Dalgaard *et al.*, 2007; Williams *et al.*, 2008). These studies have generally shown approximately five to ten fold reductions in carbon footprint values for white meats from non-ruminants such as pigs and poultry, than for red meat from ruminant animals. A key factor in this difference is the enteric CH_4 emissions from forage digestion by ruminant animals. However, it must be recognised that pigs and poultry are generally fed on grains from crops on land that could alternatively be used for crops for direct consumption by humans. In contrast, ruminants can utilise feed sources that cannot be utilised by non-ruminants and much of the grassland in NZ used for sheep and beef cattle is unsuitable for cropping or for other food production purposes. Thus, evaluation of systems and products using LCA typically extend beyond only carbon footprinting and include a wider range of environmental indicators. While sheep and beef farming can result in a higher carbon footprint than some other food options, it may have less impact from some other environmental emissions. For example, eutrophication which is more relevant at a catchment scale can be lower from sheep and beef farm systems due to relatively low nitrogen and phosphorus losses to waterways than other intensive food production systems (McDowell & Wilcock, 2008). Comparisons of different systems and products also need to extend to the use of resources such as energy and water. Similarly, energy use may be lower on some pastoral agricultural systems.

ENERGY USE

Fossil fuels and electricity represent important energy sources used throughout all parts of the economy, including agriculture. Depletion of reserves of fossil fuels is resulting in increased difficulty in accessing them as evidenced by the greater off-shore drilling and extraction for oil. As the name indicates, fossil fuels are a source of carbon derived from ancient vegetation fossilised within the earth, which on extraction and use result in GHG emissions, predominantly as CO_2. The energy sector in NZ contributed 45% of the national total GHG emissions in 2008 (Ministry for the Environment, 2010). Large increases in emissions from the energy sector have occurred since 1990, with a 69% increase primarily from road transport and a 122% increase from electricity generation (Ministry for the Environment, 2010). New Zealand is fortunate in having 73% of its electricity derived from renewable sources, with 57% of the grid-mix from hydro, 11% from geothermal and 4% from wind sources (Ministry of Economic Development, 2010). Thus, we have a relatively low GHG profile for each MJ of energy used from electricity compared to some other countries such as Australia and the USA where coal is the predominant source. While wind generation of electricity in NZ was only 0.4% in 2004 there has been a large increase in the number of turbines commissioned during the last few years. Similarly, there has been an increase in geothermal plants in an effort to increase the contribution from renewable energy.

FIGURE 6: Total energy use efficiency (MJ/kg fat and protein corrected milk (FPCM)) in three DairyNZ farmlet systems varying in rate of nitrogen fertiliser (N) use and maize silage (MS) input (13t DM/ha/year), and the New Zealand average dairy farm updated from Basset-Mens *et al.* (2009). Fertiliser (fert) inputs are separated into those applied to pasture or to maize. 170N = 170 kg fertiliser-N/ha/year.



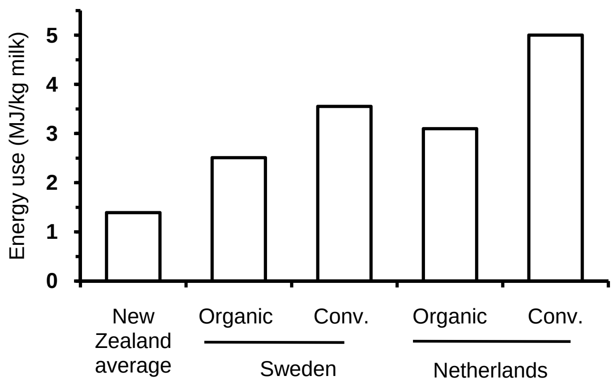
Energy use in New Zealand agricultural systems

The total energy inputs and use of fossil fuels has been estimated for the average NZ dairy farm system (Basset-Mens *et al.*, 2009) and has been updated based on recent data (Ledgard *et al.*, 2011). This analysis showed that the total energy input via electricity and fuel use throughout the cradle-to-farm-gate stages was equivalent to 1.3 MJ/kg milk (fat and protein corrected milk (FPCM) to enable comparison with other studies). The corresponding value for fossil fuel use was 1.1 MJ/kg FPCM. The major contributor to fossil fuel use was from N fertiliser at 58% of the total and most of this was associated with the manufacturing stage. Other contributors were use of phosphorus, potassium and sulphur fertilisers at 19% (mainly due to fuel use in shipping raw materials to NZ for manufacturing), 11% for fuel use (associated with farm activities including supplementary feeding and animal movement) and 11% for electricity (the fossil fuel component of the electricity used mainly for dairy shed use).

The energy use efficiency will vary with the farming system used. This was evaluated in a DairyNZ trial comparing different farm systems and the NZ average farm (Figure 6). It showed the greatest efficiency for the nil N fertiliser system, higher energy use/kg milksolids in a system using 170 kg fertiliser-N/ha/year and a further increase in a system with the addition of maize silage at 2.5 t DM/cow. The energy use efficiency for the NZ average farm was similar to that of the farm system using 170 kg fertiliser-N/ha/year plus feeding maize silage at 2.5 t DM/cow. While the NZ average farm used less N fertiliser and much less brought-in feed it also had much lower milksolids production per hectare.

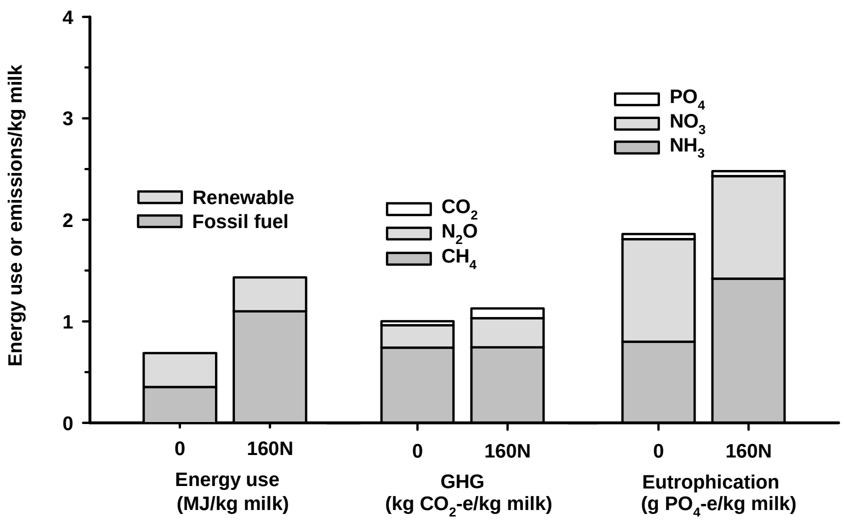
Comparison of the NZ average dairy farm and average organic or conventional dairy farm systems in Sweden and the Netherlands (Figure 7) showed much lower total energy use/kg FPCM in the NZ farm system. This can be attributed in part to the all-year grazing of perennial pastures in contrast to the European systems with high fossil fuel use associated with cow-housing, cut-and-carrying of feed and high use of brought-in feed. The higher energy efficiency of the organic farm systems was due mainly to greater use of out-door grazing of pasture and not using N fertiliser.

FIGURE 7: Total energy use efficiency (MJ/kg fat and protein corrected milk) in the New Zealand average dairy farm (from Figure 6) and organic or conventional (Conv.) dairy farm systems in Sweden (Cederberg & Mattsson, 2000) and the Netherlands (Thomassen *et al*., 2008).



Total energy use and fossil fuel consumption on sheep and beef farms in NZ is low due to the relatively small component of supplementary feeding and forage cropping. In the recent studies on NZ sheep and beef farm systems, the average energy use was estimated at 1,160 MJ/ha/year, which can be compared with that for the average NZ dairy farm of 18,100 MJ/ha/year. However, these values need to be related to the output of product. On a protein production basis the use of fossil fuels equates to approximately 29 MJ/kg meat protein to the sheep and beef farm gate and about 35 MJ/kg milk protein for the NZ average dairy farm. On sheep and beef farm systems about two-thirds of the fossil fuel use was associated with fertilisers (raw material transport and manufacturing), with fuel and electricity use constituting about 22% of the total. Fossil fuel use on the NZ average dairy farm system was also dominated by fertiliser use with the main contributor being N fertiliser (58% of total; Ledgard *et al*., 2011).

FIGURE 8: Energy use, GHG (greenhouse gases as CO_2 equivalents (CO_2-e)) emissions and eutrophication (as PO_4 equivalents (PO_4-e)) potential based on application of life cycle assessment in dairy farmlet systems with clover/grass pasture receiving no nitrogen fertiliser or grass-only pasture receiving fertiliser-nitrogen (N) at 160 kg N/ha/year (160N).



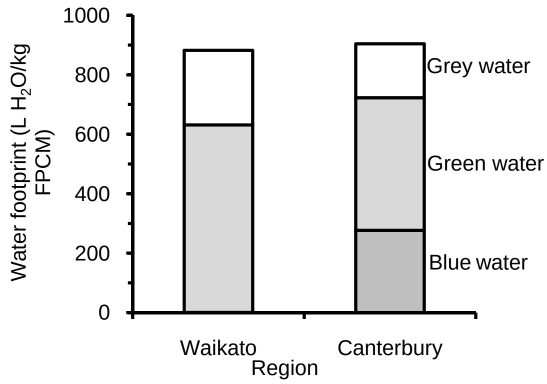
Nitrogen fertiliser versus clover N_2 fixation

Production of N fertiliser has a high fossil-fuel energy requirement, particularly associated with the ammonia production stage which commonly uses natural gas, and in total can equate to approximately 60 MJ/kg N (Jenssen & Kongshaug, 2003). In contrast, the fixation of atmospheric N_2 by clover uses photosynthetically-fixed carbon and energy via sunlight.The rate of N fertiliser use on NZ dairy farms has increased over time with a six-fold increase between 1990 and 2005 (Ministry for the Environment, 2010). A direct comparison of fertiliser-N versus fixed-N from clover was made using results from a long-term dairy farmlet system with no N fertiliser use and reliant on biological N_2 fixation by clover, which was measured over five years at an average of 160 kg N/ha/year (Ledgard *et al.*, 2009). This is compared with an associated hypothetical system based on ryegrass-only pasture receiving urea-N at 160 kg N/ha/year and was assumed to achieve the same productivity as the nil-N clover/ryegrass pasture. The comparison showed that total energy use and fossil fuel use in the 160 kg N/ha/year system was 109 and 149% higher per kg of milk than the nil-N system, respectively (Figure 8). Total GHG emissions and eutrophication potential per kg milk were 12 and 33% higher, respectively, for the N-fertilised system. This evaluation indicates that practices to enhance clover growth and symbiotic fixation of atmospheric N_2 represent an option to reduce N fertiliser use and thereby reduce energy use and environmental (GHG and eutrophication) emissions.

WATER FOOTPRINTING

Globally, water consumption and pollution have been identified as key resource use issues. Agricultural production is the major water user (Food and Agriculture Organisation of United Nations, 2006). A range of methods have been and are being developed in the new research area of water footprinting, with each varying in the way in which they account for water consumption and impacts (Milà i Canals *et al.*, 2009; Ridoutt & Pfister, 2010; Hoekstra *et al.*, 2011). Most attention has been given to the total water footprint calculation method of the Water Footprint Network 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 & Hoekstra, 2010). These figures consist of blue, green, and grey water. The blue water footprint is the volume of groundwater and surface water consumed, that is withdrawn and then evaporated. The green water footprint is the volume of water evaporated from soil. The grey water footprint is the volume of fresh-water that is required to assimilate the load of pollutants based on existing ambient water quality standards (Hoekstra *et al.*, 2011).The main contributor to such high volumetric water

FIGURE 9: Blue water (volume of groundwater and surface water consumed, that is withdrawn and then evaporated), green water (volume of water evaporated from soil) and grey water (volume of fresh-water that is required to assimilate the load of pollutants based on existing ambient water quality standards) footprint of average dairy farms in the Waikato and Canterbury region (Zonderland-Thomassen & Ledgard, 2011). FPCM = Fat and protein corrected milk.



numbers 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.

A study by Zonderland-Thomassen (Unpublished data) resulted in total water footprint estimates of 882 litre H_2O/kg FPCM for a rain-fed Waikato dairy farm for which 72% was from green water, 28% from grey water at 28% and only 0.1% from blue water (Figure 9). Total water footprint of an irrigated Canterbury dairy farm was 904 litre H_2O/kg FPCM, of which 49% was from green water, 31% from blue water and 21% from grey water.

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.*, 2010) 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 high 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-e (water equivalent)/kg FPCM.

This is, however, only one approach. The methodology on the topic of water footprinting is developing. At present there are no internationally agreed methods. More research is needed to account for spatial and temporal factors, among others. For example, although it seems water availability in NZ on an annual basis is of limited concern, seasonal droughts in specific regions are of considerable importance.

CONCLUSIONS AND IMPLICATIONS

LCA is a useful tool to evaluate the resource use and environmental efficiency of agricultural systems and practices, and to account for these along the whole supply chain or life cycle. Its application to agricultural products is most evident with carbon footprinting, where it is being used at industry, policy and consumer levels including for eco-labelling of products. Carbon footprinting of pastoral agricultural products has generally shown relatively high numbers compared to alternative food products such as grains or even white meats. This has led various authors and politicians to suggest the public should consume less of these products or substitute them for low emission alternatives. In the UK, Garnett (2007) proposed that much of the land could be used for growing crops for direct consumption and for biofuels, with livestock relegated to upland areas unsuitable for crops. Debate on such issues is important although it should not overlook the many other benefits like nutritional value, production of valuable co-products and livelihoods associated with livestock systems (Food and Agriculture Organisation of United Nations, 2006). It also highlights the importance of the agricultural sectors being proactive and working to reduce their GHG emission intensity.

The carbon footprint analyses presented in this paper indicate that NZ agricultural products have a relatively low carbon footprint compared to some of our overseas competitors. However, our distance from markets and the increasing demand for carbon reduction plans from our overseas markets mean that it is important that we act to reduce the carbon footprint of products in future. In the case of the sheep and beef sector, this will be most easily achieved by continuing with the ongoing focus on improved productivity, that is producing more meat per kg pasture consumed by the animal. While this is also important for dairying it is critical that wider life cycle analyses are carried out where practices such as increased fertiliser use, brought-in feeds and use of forage crops, are being integrated on farm. Wider life cycle analyses will avoid "pollution swapping" issues. It is also important that the debate around product carbon footprinting extends to consider the nutritional value to humans of products and to account for wider social and environmental considerations.

Research on total energy and fossil fuel use in NZ farms has shown a benefit of our relatively low input systems with grazing of perennial pastures. The increasing use of high energy-demanding N fertiliser and some brought-in feeds is gradually diminishing this advantage. A renewed focus on the better use of pasture legumes for N inputs via N_2 fixation is warranted from an energy use and environmental efficiency perspective.

LCA is a useful tool for application in system design and optimisation to ensure efficiency of use of key resources such as energy, nutrients and water and to increase environmental efficiency of product supply to consumers.

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