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Carbon footprinting of New Zealand lamb from the perspective of an exporting nation

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Implications

- Contributors to the carbon footprint of New Zealand lamb exported to the United Kingdom across the life cycle were the cradle-to-farm-gate (80%; mainly animal-related emissions), processing (3%), retail/consumption/waste (12%), and shipping (a small component at 5%).
- Sheep farming uses low inputs and all-year grazing of perennial grasslands. Nevertheless, large efficiency gains have occurred with a 22% smaller on-farm carbon footprint compared with 1990 from increased lambing percentage and lamb growth rates.
- In the wider sustainability context of food production, sheep have a low environmental impact and utilize grassland on hills and steepland that have limited other uses.

Key words: coproduct, grassland, life cycle assessment, reduction

Introduction

Sheep meat constitutes a relatively small proportion of the meats consumed globally (approximately 6%), and in developed countries it is a niche product. New Zealand (**NZ**) is the world's largest exporter of lamb at more than 40% of total global exports (FAO, 2008).

Lamb from NZ is exported widely and the main markets are in northern hemisphere countries, with the largest single market being the United Kingdom (**UK**). This means a long transportation distance to markets with associated costs and implications for "food miles" and related greenhouse gas (**GHG**) emissions.

This paper reports on a research study on the carbon footprint (i.e., total GHG emissions throughout the life cycle of a product) of NZ lamb exported and consumed in the UK. It also considers the wider implications and context for meat production and GHG emissions reduction.

International and NZ Lamb Production

China is the world's largest producer of sheep meat at nearly 2 Mt, followed by Australia at 0.8 Mt and NZ at 0.6 Mt (FAO, 2008). However, most Chinese production is consumed domestically, whereas NZ exports about 92% of its total lamb production. Internationally, sheep production is diverse and sheep are multi-purpose animals producing meat, milk, skins, and wool, although meat production is their primary function (Zygoyiannis, 2006). Sheep are commonly grazed on native or introduced forages and are able to forage and survive in many areas where cattle perform poorly.

In NZ, sheep are typically farmed with beef cattle and sometimes with deer on long-term perennial grasslands. These farms are predominantly located on hill or high country, and pressure from other greater profitability farming systems, such as dairying, means that sheep numbers are decreasing and they are increasingly being confined to more extensive steeper grassland areas. Poor economic returns from lamb and sheep coproducts over the past decade have resulted in emphasis on the remaining farms to increase lamb productivity and efficiency to remain viable.

Sheep farming systems in the temperate climate of NZ are based on all-year grazing of permanent perennial grass and white clover pastures, no use of brought-in feeds, and low inputs. Fertilizer nitrogen (N) use on NZ sheep and beef farms averages approximately less than 10 kg of $N \cdot ha^{-1} \cdot year^{-1}$, and much of this is used for winter feed for cattle (B+LNZ, 2010). A key feature of farm management is the use of grazing practices that maintain high-quality pastures, particularly for finishing lambs at high growth rates.

The average lambing from ewes is approximately 125%, and most lambs are finished to a final live weight of 40 kg within 5 to 9 months. Lambing in early spring means that the pasture growth pattern matches feed demand and most lambs are processed in summer/autumn. After processing, most NZ lamb meat is shipped to the northern hemisphere in their winter/spring period, supplying the market during a period of low local lamb supply.

Why Undertake a Lamb Carbon Footprint Study?

Consumer awareness about carbon footprinting of products is high in certain markets, and this has been led by supermarkets, particularly in the UK. This has resulted in a demand for information on the carbon footprint of products supplied to some major supermarket chains or to intermediate businesses that supply them. For NZ exporters, interest in footprinting has been accentuated by NZ's long distance from many markets and possible concern about the related transport GHG emissions.

Within NZ, the government has also initiated an emissions trading scheme, which has put a charge on GHG emissions from fossil fuel and electricity use. In addition, animal-related emissions from agriculture are scheduled to be phased into the scheme (MfE, 2011). These market

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and domestic policy drivers have resulted in the need for producers and exporters to be aware of their contribution to the carbon footprint of products and of footprint reduction opportunities.

Carbon Footprint Methodology

An attributional life cycle assessment (**LCA**) approach (e.g., Thomassen et al., 2008) was used to estimate the carbon footprint of NZ lamb exported by ship to the UK, cooked, and consumed by a UK household and including waste (uneaten lamb and sewage) stages (Figure 1). The functional unit was 1 kg of processed NZ lamb meat purchased by a UK consumer.

Emphasis was on the whole life cycle and applying methods that complied with ISO14044 (BSI, 2006) and PAS2050 (BSI, 2008), particularly since the UK is a major market for NZ lamb. To conform to PAS2050, customer travel was excluded but sensitivity analysis was used to examine effects of its inclusion.

Survey data from Beef + Lamb NZ (**B+LNZ**, 2010) covering more than 400 sheep and beef farms throughout NZ was used to calculate GHG emissions from different farm classes and to determine an NZ weighted average. Animal production data were used in an energy-based (tier 2) model (Clark et al., 2003) to estimate dry matter intake for the sheep breeding and lamb production system. Biophysical allocation (e.g., Flysjö et al., 2011) was used to allocate GHG emissions between animal types, and economic allocation (5-year average) was used to allocate between lamb, mutton, and wool production from sheep. New Zealand-specific emission factors for methane (enteric and fecal), and nitrous oxide from excreta and leached N were used based on the NZ GHG Inventory (MfE, 2007). Other emissions accounted for included embodied CO_2 emissions from electricity and fuel use, CO_2 from fertilizer production and urea and lime application to soil, and refrigerant emissions (from refrigerated containers, chillers/freezers, and retail and household refrigerated cabinets) (Ledgard et al., 2009a).

Primary data on energy use, consumables, refrigerant leakage, wastes, and effluent processing were collected from lamb processing plants from throughout NZ (covering more than 40% of total lambs processed). Data on typical shipping distance to the UK (20,750 km) were combined with a conservatively high emission factor for refrigerated container shipping of 0.05 kg of CO_2-equivalents (**CO_2 eq.**)/tkm (including fugitive emissions of refrigerants) to estimate shipping GHG emissions. Secondary data were used in estimating GHG emissions from retail (Carlsson-Kanyama and Faist, 2000), household (including cooking; Foster et al., 2006), and waste stages. Emissions associated with the production of capital items, transport of consumers to and from the point of retail purchase, and changes in soil carbon were all excluded (according to PAS2050; BSI, 2008).

Main Findings and Life Cycle Implications

The carbon footprint averaged 19 kg of CO_2 eq./kg of lamb meat, with 80% from the cradle-to-farm-gate (mainly animal methane and nitrous oxide 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; Ledgard et al., 2009a, 2010). Thus, all stages throughout the life cycle contribute to GHG emissions and can contribute to reduction of the carbon footprint. Sensitivity analysis was used to examine effects of alternative practices at all stages of the life cycle. At the consumer stage, inclusion of consumer transport to purchase the meat added up to 7% to the total carbon footprint depending on the mode of transport and food purchasing practices. The method of cooking by the consumer was also important with cooking-related emissions being 20% greater by roasting the lamb compared with frying it.

At an NZ lamb processor level, emissions were most dependent on energy source, energy use efficiency, and effluent processing system. For

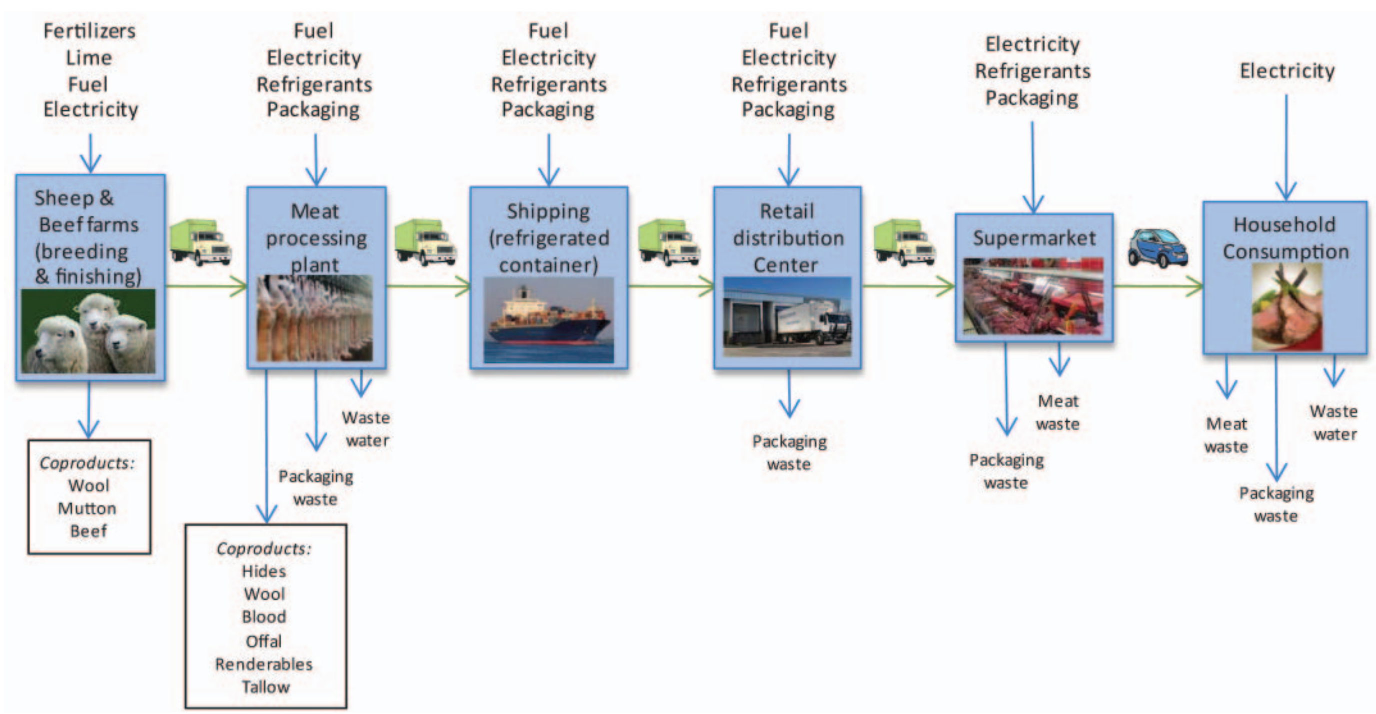

Figure 1. Simplified system diagram showing the main life cycle stages, inputs, outputs, flows, and coproducts.

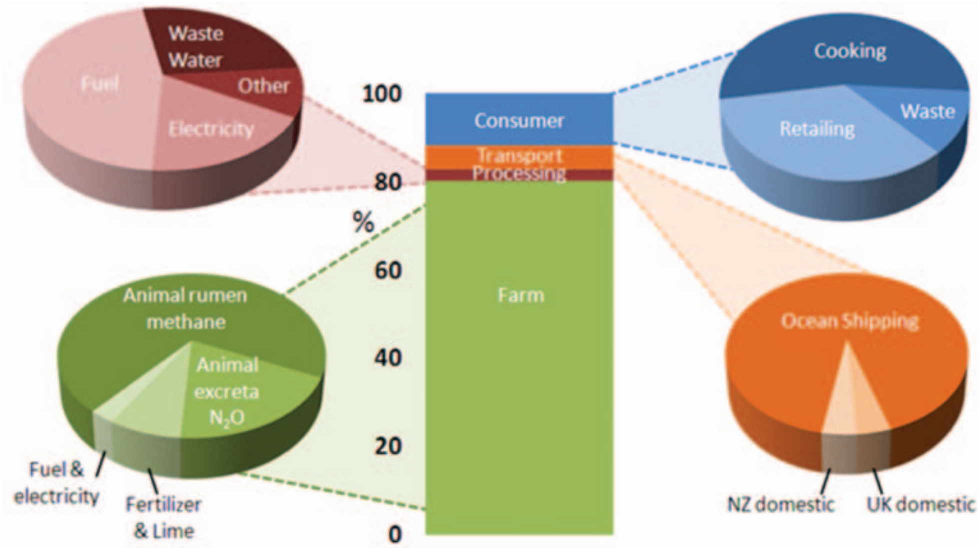

Figure 2. Relative contribution from the main life cycle stages to the carbon footprint of New Zealand (NZ) lamb consumed in the United Kingdom (UK; Ledgard et al., 2010).

example, moving from an anaerobic waste water system to an aerobic one could potentially decrease processing GHG emissions by up to 30%. In practice, improvements at most NZ lamb processing plants have been made over time by shifting from anaerobic pond processing of effluent (with associated methane emissions) to land application and using the waste as a nutrient source for grass growth. Similarly, processors have increased energy use efficiency and moved away from burning coal to the use of gas or other energy sources. One processor (Silver Fern Farms, NZ) has recently switched to the use of a Bubbling Fluidised Bed boiler, which is able to utilize sludge from waste water treatment and woodchips as fuel sources instead of coal, which had been used.

Technological changes can affect the supply chain and the carbon footprint. For example, lamb has traditionally been frozen and shipped to the UK, but in the past decade there has been a large increase in vacuum-packed chilled lamb providing increased quality and shelf-life of up to 14 weeks. Sensitivity analysis indicated that the chilled lamb supply chain used less energy compared with the freeze chain, but it only decreased the total carbon footprint by approximately 0.7%.

In the transportation stages, shipping was the main contributor to total transport-related emissions. However, it was also identified as being very efficient, with emissions per ton per km (excluding refrigeration) at about 0.01 kg of CO_2 eq. compared with about 0.08 for trucking and 0.3 for a household car (based on various modeled analyses). In this study, a conservatively large emission factor was used for shipping refrigerated containers of 0.05 kg of CO_2 eq. per ton per kilometer (including backhaul of an empty container), whereas others have used values of less than one-half of this (e.g., 0.018 by Williams et al., 2008). Thus, the food-miles associated with transportation of product to market were only a minor contributor to the total carbon footprint.

Farm GHG Emissions and Reduction Opportunities

The cradle-to-farm-gate stage was the main contributor to the carbon footprint, and this was predominantly from animal-related methane and nitrous oxide 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 evident from the reduction in methane emissions per kilogram of sheep meat produced in NZ (Figure 3). The main reasons for this are an increase in the lambing percentage of ewes (from about 100% in early 1990s to 125% in 2008), increased growth rate of lambs, and finishing lambs at heavier weights (Morris, 2009). Thus, in 2009, NZ sheep farms produced slightly more lamb meat by weight compared with 1990, but from a 43% smaller national flock (B+LNZ, 2010). This has been estimated to coincide with a reduction in GHG emissions from cradle-to-farm-gate by approximately 22% (Ledgard et al., 2010). Ongoing improvement in the NZ sheep sector is also occurring through an increase in the proportion of ewe hoggets mated (again resulting in more lamb production for each kilogram of feed eaten by the breeding flock). In practice, the main driver of these reductions in GHG emissions is the need for increased farm profitability through increased on-farm efficiency.

Sensitivity analyses indicated limited ability to reduce the carbon footprint by targeting other sources of on-farm GHG emissions. One possibility examined was to cease use of N fertilizer on farm because it has high manufacturing-related emissions (e.g., Ledgard et al., 2011). However, bearing in mind the current very low N fertilizer use on NZ farms and the reduced productivity from ceasing its use, the effect was calculated to be a reduction in carbon footprint of <1%. Nevertheless, where N fertilizer use is significant, the integration of clovers in pastures that can fix atmospheric N_2 and replace N fertilizer has the potential to greatly reduce fossil fuel use and decrease the carbon footprint. For example, Ledgard et al. (2009b) estimated a 12% reduction in carbon footprint for an NZ dairy system receiving 160 kg of $N \cdot ha^{-1} \cdot year^{-1}$ by substituting fixed-N for fertilizer-N.

How Does the Carbon Footprint of NZ Lamb Compare with That from Other Studies?

There have been few other studies that have examined the carbon footprint of lamb, and they have all stopped at the farm-gate or the retail distribution center. For the carbon footprint from the cradle-to-farm-gate,

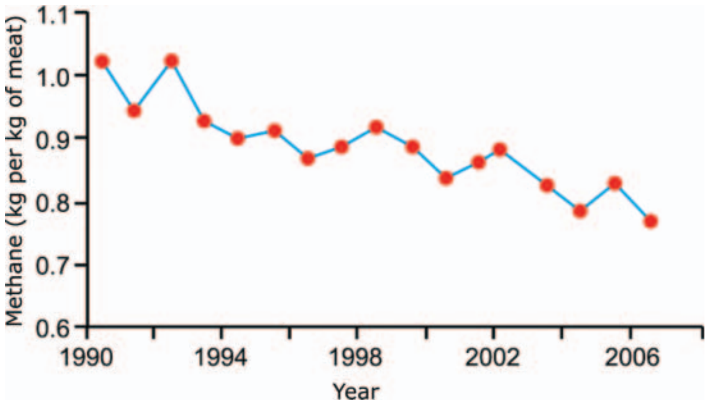

Figure 3. Calculated methane emissions from New Zealand average sheep meat based on B+LNZ (2010) data and use of the New Zealand greenhouse gas inventory methodology (MfE, 2007).

estimates for various studies in kilograms of CO_2 eq. per kilogram of lamb body weight were 12.9 or 51.6 for 2 Welsh case study farms (Edwards-Jones et al., 2009; the high value was due mainly to specific peat soil N_2O emissions), 10 for an average Irish farm system (Casey and Holden, 2005), and 8.6 in the current study. Williams et al. (2008) estimated GHG emissions to a UK retail distribution center for lambs produced in the UK or NZ at 14.1 and 11.6 kg of CO_2 eq./kg of lamb product, respectively. However, it must be noted that there were differences in methodology across all of these studies, particularly for methane estimation method (e.g., tier 1 versus tier 2 methods; IPCC, 2006), different Intergovernmental Panel on Climate Change (IPCC) emissions factors, different system boundaries, and different allocation methods. This means that the values outlined above cannot be directly compared, although Williams et al. (2008) applied the same methodology in comparing lamb from 2 countries. The strong impact of methodology highlights the need for research papers to report all methods and data used so that others might recalculate a carbon footprint for comparative purposes.

More importantly, the variability between studies in the methods used emphasizes the desirability of defining and agreeing on a methodology such as through product category rules (BSI, 2008). This is particularly important in methodology aspects for products where there is a strong influence on the final carbon footprint value (e.g., for allocation between coproducts). The International Dairy Federation recently released a common methodology for dairy carbon footprinting through a common process involving international dairy companies and LCA researchers, and this represents an ideal process. The International Meat Secretariat has supported the same approach to be developed for a common methodology for lamb carbon footprinting, and this is currently underway.

What Factors Influence Variability Between Studies?

As well as differences in methodology between studies, the carbon footprint of lamb can vary with the farm system used and between individual farms. Similarly, there will be variation between different processors' contribution to the footprint (e.g., by about 2-fold per kilogram of lamb processed in the current study) and at other stages, including in retail and consumer practices.

The few individual case farms and farm types examined in the current study showed variation in cradle-to-farm-gate GHG emissions of about 2-fold. Paradoxically, the least emissions were from Merino sheep produced on high country, even though they had the least efficiency of productivity (i.e., least lambing percentage, lamb growth rates, and finishing body weights). This was simply an artefact of economic allocation being used, with greater allocation of total sheep emissions to wool (and therefore less to meat) for Merinos due to their much greater monetary returns per kilogram of wool compared with that for the strong wool (used for carpets) produced by other NZ sheep breeds.

The magnitude of a carbon footprint will depend on the range of coproducts produced and their value or significance or both. Lamb produces a range of coproducts including meat, wool, hide (used for making leather), blood, offal (some components representing delicacies for certain cultures, such as stomach lining or tripe), tallow (with a range of uses including for biofuels), and renderable components that are processed into products, such as animal feeds. If the latter 4 coproducts were worthless and went to waste (e.g., to landfill or to the effluent system, as had happened to a varying extent in the past), then a greater component of total lamb GHG emissions would be allocated to meat. Whereas the use of economic allocation may accentuate these differences, other allocation methods such as system expansion will also be influenced by coproducts with other uses and value. However, meat is the most valuable product from lamb and currently the nonmeat coproducts may constitute about 50% or more of the body weight but usually provide less than 20% of total economic returns.

How Does the Carbon Footprint of Lamb Compare with That of Beef or Other Meats?

Generic studies comparing meat types have generally shown much smaller carbon footprint values (by about 5- to 10-fold) for white meats from nonruminants (pigs, poultry) than for red meat from ruminant animals (e.g., Dalgaard et al., 2007; Williams et al., 2008). A key factor in this difference is the enteric methane emissions from forage digestion by ruminant animals.

There are many more published studies on the carbon footprint of beef than of lamb. For the cradle to-farm-gate stage, most beef studies are within the range of 7 to 19 kg of CO_2 eq./kg of body weight, 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 lamb based on generic models that accounted for the range of farm systems that exist. Their estimate for GHG emissions per kilogram of body weight 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 showed smaller carbon footprint values for average NZ lamb than for NZ beef (average for traditional suckler breeding and bull beef systems), at 8.6 and 10.5 kg of CO_2 eq./kg of body weight, respectively (Ledgard et al., 2010; M. Lieffering, S. Ledgard, M. Boyes, and R. Kemp, AgResearch, New Zealand, unpublished). This smaller carbon footprint for lamb can be attributed to greater fecundity in sheep (e.g., 125% lambing by ewes compared with 95% calving by breeding cows), greater average growth rates in lambs, and wool as a coproduct from sheep. However, it must also be recognized that in most countries a significant component of the beef is derived from cull dairy cows, which have a small carbon footprint, and in NZ its inclusion brings the weighted average carbon footprint for beef at the farm-gate down to the same value as that for lamb. This further highlights the importance of accounting for whole production systems and coproducts when carrying out a carbon footprint analysis.

The carbon footprint values outlined above all refer to averages for different systems or countries. In practice, there is a large variation between individual farms within a farm system or country, and this variation is likely to overlap the apparent differences between the published averages. Although some of this variation between farms is due to inherent site factors and therefore is unmanageable, much of it can be attributed to differences in farm management practices and provides opportunities for improvement.

A Carbon Footprint Is Just One Environmental Indicator

Whereas lamb and other red meats have a greater carbon footprint than white meats, there are context issues and other environmental indicators that should be considered in assessing the wider sustainability of food products. 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 utilize feed sources that cannot be utilized by nonruminants, and in the case of sheep this is largely grassland that is on land unsuitable for cropping. For example, in the UK the latter includes upland and hill areas, whereas in NZ it also includes steep hill country and high-altitude tussock country. This land is generally unsuitable for other food production purposes.

Life cycle assessment is widely used in determining the carbon footprint of products, but it is also a useful tool for examining resource use efficiency and other environmental indicators. Food production based on low energy use, and particularly low fossil fuel use, is desirable to ensure supplies of fossil fuels are available for other more critical requirements. Lamb production from long-term grasslands typically has low fossil fuel use compared with that from intensive agriculture such as dairy farming. For example, in the NZ lamb study the average fossil fuel use was 26 MJ/kg of protein produced to the farm-gate stage in comparison with about 210 MJ/kg of protein for milk produced in the Netherlands (Thomassen et al., 2008).

Lamb production on grasslands also has a low impact on water quality. In NZ the average N concentrations in waterways measured in sheep-dominant catchments equated to an N loss of 3 kg of N·ha^{-1}·year^{-1}, which was less than that in catchments dominated by other livestock types, but greater than the 2 kg of N·ha^{-1}·year^{-1} from forest catchments (McDowell and Wilcock, 2008). The average for NZ dairy catchments was about 27 kg of N·ha^{-1}·year^{-1}, and NZ studies with cereal crops have shown similar N leaching rates to that for dairying. Although there was less difference across catchments and livestock types in phosphorus loss to waterways, sheep catchments again had the least losses (other than forests).

Another feature of landscapes grazed by sheep is the relatively high biodiversity. In NZ, most sheep farms have significant areas of native or planted trees, particularly on steeper and erosion-prone areas. Although offsetting of GHG emissions is not included in carbon footprint analyses, at an individual farm and national GHG inventory level the recently forested areas represent significant carbon sinks. All carbon footprint analyses discussed in this paper take no account of carbon sequestration, in keeping with requirements of the PAS2050. However, some carbon footprint protocols are reviewing possible inclusion of carbon sequestration in soil. Surveys of soil carbon status on sheep and beef farms on NZ hill country have shown that amounts are increasing (Schipper et al., 2010), and similar conclusions were drawn from French research in temperate grasslands (Sousanna et al., 2004). More research is needed to better understand processes affecting this and the temporal pattern of carbon accumulation so that it can be appropriately accounted for in carbon footprinting. Additionally, large losses of CO_2 occur from cultivation during crop production due to oxidation of soil carbon, whereas the carbon in grassland soils is important for carbon retention.

Concluding Comments

Low environmental impacts, including a low carbon footprint, should be one goal in our quest for efficient food production systems from our global landscapes. Sheep farming systems are important because they utilize difficult grassland landscapes with limited other uses and the lamb produced from it is a valuable niche source of red meat globally. From an exporting nation's perspective, NZ provides a complementary out-of-season supply of quality lamb to northern hemisphere countries with efficiency goals including a low total carbon footprint. From a global perspective of limiting GHG emissions, there is a desire for low carbon footprint food systems irrespective of the source of supply, provided other acceptable standards of food quality, environment, and welfare are met. This places pressure on exporters to be able to supply product into overseas markets with a low total carbon footprint and consequently on achieving ongoing reductions in the carbon footprint of their products.

The study of the carbon footprint of NZ lamb covered all the "cradle-to-grave" stages, and more whole life cycle studies are required for other animal and food options. The lamb study showed that GHG emissions are dominated by utilization of grassland by sheep at the farm stage. However, it also showed that there have been large gains in efficiency, with a reduction in the carbon footprint over time at the farm level of over 20% since 1990. Other contributors, including consumers, to the carbon footprint of the lamb life cycle can also reduce the footprint through improved technological, management, and behavioral practices.

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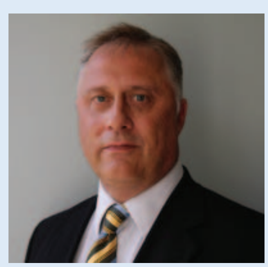
Dan Coup is trade and economic manager for the Meat Industry Association of New Zealand, the organization representing New Zealand meat packers and exporters. Dan has a background in biological sciences and economics. His current role focuses on trade policy but also incorporates climate change policy issues, including New Zealand's domestic cap and trade legislation, and product-level carbon footprinting for overseas customers.



Ben O'Brien is general manager of Market Access at Beef + Lamb New Zealand, which is the representative body of New Zealand's sheep and beef farmers. He has responsibility for managing his organization's activities in trade policy and technical issues, including sustainability. O'Brien has worked in the New Zealand meat industry for more than 20 years covering a wide range of responsibilities including research and development and quota management. He is a member of the International Meat Secretariat's Sustainable Meat Committee and has an interest in promoting a single international greenhouse gas life cycle analysis methodology for lamb.