LCA: NEW ZEALAND MERINO WOOL TOTAL ENERGY USE

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Images of a clean and green New Zealand environment are no longer enough to satisfy increasingly sophisticated customers that are demanding validation of environmental sustainability claims. This paper reports the findings of research that developed a detailed inventory of resource inputs for New Zealand merino wool and assessed its total energy use profile relative to other textiles. Total energy use was studied using LCA methodology. The system boundary included the production and use of all farm inputs, wool processing and shipping wool top to China. Total on-farm energy use average 890 MJ/ha and 230 MJ/stock unit (s.u.). Fuel and electricity accounted for 50% of total farm energy use, fertiliser 36%, purchased feed and agrichemicals 5%, and capital 9%. Total energy productivity per tonne of wool is very dependant upon the allocation methodology. Resource allocation was base on mass, being the only underlying physical property common to all economic farm outputs. Wool top landed in China consumes 48,100 MJ/tonne dry top. An economic allocation model increases the energy footprint to 76,575 MJ/tonne dry top. In the merino wool life cycle from farm to spinning mill in China on-farm inputs account for 52% of total energy use, wool processing 45% and transport is just 3%. Results of this study show that New Zealand merino wool production consumes 42% of the energy need to manufacture polyester, 30% of acrylic and just 21% of the energy need to manufacture nylon to the spun fibre stage. New Zealand merino fibre production and early stage processing uses significantly less energy than synthetic fibres.

Keywords: Merino wool; synthetic fibre; LCA; total resource and energy use; energy productivity

1 Background

The production of merino fibre in New Zealand is associated with stunning vistas and an expectation of environmental purity. The extensive all year round grazing system employed by the majority of merino farmers is based on low resource inputs and high productivity.

While farmers and marketers of New Zealand merino wool highlight their environmentally sustainable production systems, consumers and retailers are increasingly scrutinising those systems and expect that claims of sustainability and environmental performance can be validated.

The challenge is to compare substantially different materials that often perform similar functions, such as synthetic and natural fibres, including wool, cotton, and linen (flax) in a meaningful and valid way. All have an impact on the environment in their production, use and disposal.

This project, funded by MAF's Sustainable Farming Fund (www.maf.govt.nz/sff) and the New Zealand merino industry, set out to investigate the total energy profile of merino wool fibre production and early stage processing. The first aim was to establish baseline information on merino wool's overall resource use, energy consumption, and environmental impacts by establishing a detailed on-farm inventory and set of total energy indicators. The second aim was to compare the merino fibre energy indicators with published data on other textiles.

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2 Scope

A simplified life cycle diagram for wool production is provided in Figure 1. The system boundary includes all on-farm inputs, including extraction, manufacture, delivery and use; wool scouring; top making and shipping to China. Further processing such as spinning (yarn manufacture) and knitting/weaving (fabric manufacture) were excluded from the analysis.

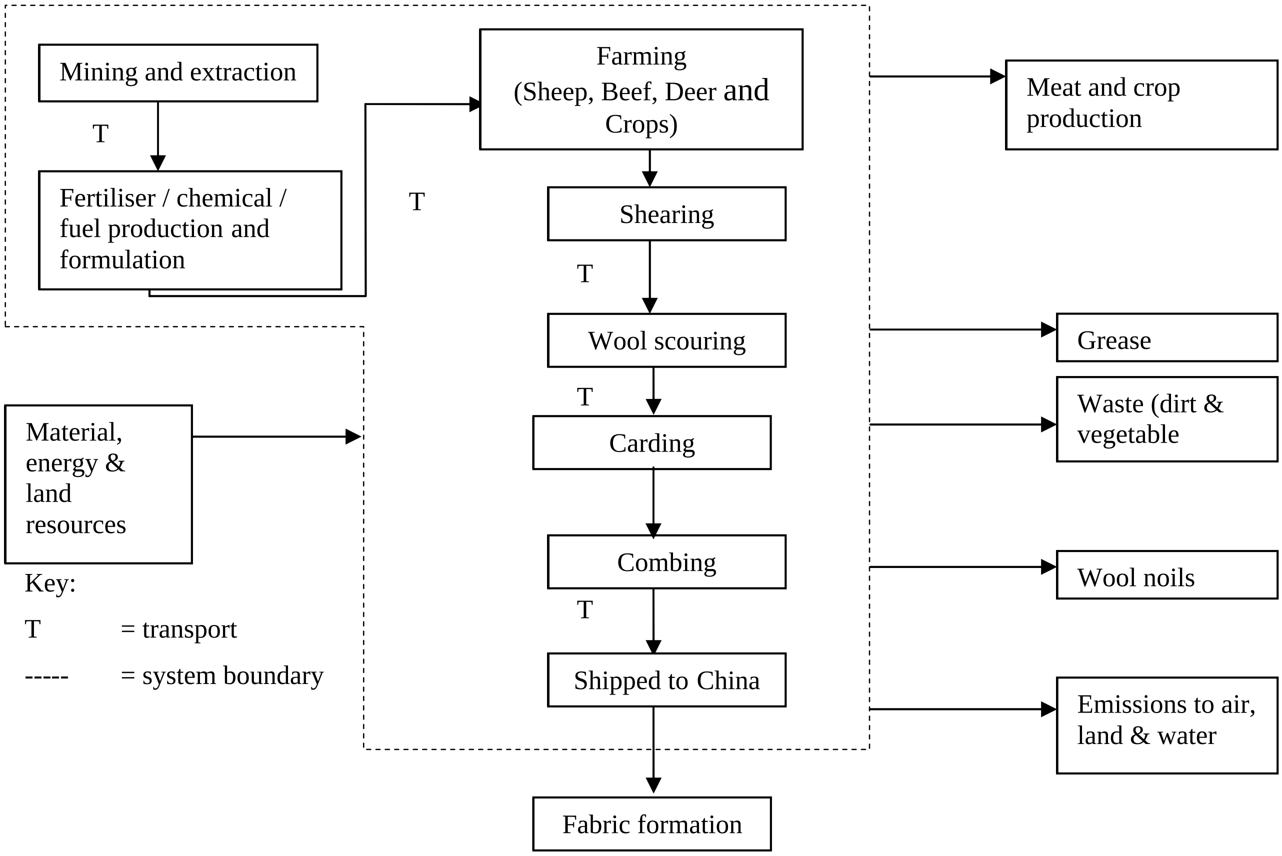

Figure 1. Life Cycle of New Zealand Wool to Fabric Formation

3 Methodology

On-farm data was collected through face to face surveys with 24 South Island sheep and beef farmers. The farms were categorised based on their stocking rate as either extensive, medium intensive, or intensive, with eight farms assigned to each category. The results are not a weighted average of New Zealand merino farming, but provide a full range of farm types from 200 hectares (ha) up to 28,200 ha. The surveyed farms were on average 900 ha larger and more intensive than the MAF Merino Model [2] [1].

3.1 Functional Unit

The functional unit is a "*tonne of dry wool top*". Wool top is the continuous, untwisted, ribbon of wool ('sliver') produced from the combing machine after the fleece has been scoured and carded. The combing process removes short and weak fibres ('noils') leaving long fibres that are aligned parallel to one another. This is the highest quality or "top-of-the-line" wool fibre, hence the name "top".

Wool top weight is the weight of clean, dry wool fibre. This is not the same as the weight of wool in an end product which will include water that has been regained after the wool drying process. The moisture content of wool in an end

[2] MAF's Merino Model is part of the annual farm monitoring of actual and short-term forecast financial and physical factors reflecting farmer, farm consultant and industry perceptions of farming trends and issues, production and financial figures.

product will be relative to the humidity of the environment, but is approximately 10%. As moisture regain of woollen products can vary, the functional unit is dry fibre.

3.2 Allocation

Merino farms in New Zealand are mixed production systems that in addition to merino sheep also include one or more of cattle, deer and/or cropping systems. Each production system is intertwined and integral to improving the overall productivity of the whole farm. The inputs are aggregated as a total for the farm and are not separately allocated to the individual animal or crop types.

Consistent with the ISO 14041:1999 standard [2], where allocation can not be avoided, farm inputs are based proportionally on an underlying physical relationship. Mass is the only consistent physical relationship between all the economic outputs, animal carcases, greasy wool and cash crops.

An alternative approach is to use economic allocation, although this is susceptible to marked variations in price across different locations and times. Farm profitability and revenue streams can be cyclical and, for an exporting country like New Zealand, are often dependant on world commodity prices and the exchange rate. By way of comparison to the mass allocation model, results based on economic allocation have been used in the discussion of this paper. No financial data was collected in this study so the MAF Merino Model [1] was applied. The MAF model shows that wool comprises 53% of total farm revenue. This may be a little higher than the farms surveyed in this study as merino sheep on the surveyed farms comprised on average 77% of the wintered animals compared to 87% in the MAF Merino Model.

All transport beyond the farm gate was allocated to wool.

Inputs in the wool scouring and top making stages were allocated proportionally based on the weight of economic outputs. The economic outputs included wool, the by-products of grease (further refined into lanolin) and wool noils, which are used in the production of less expensive woollen fabrics and felt.

3.3 Total Energy Use

Total energy use was calculated using primary energy values, which includes energy losses during conversion processes such as oil refining and electricity generation.

3.3.1 Diesel, petrol and electricity

The primary energy content for diesel and petrol is 44.3 MJ/ℓ and 40.0 MJ/ℓ respectively (Table 1), which includes an additional 23% of energy to account for the fuel’s production and delivery [3]. Fuel use by contractors was calculated based on the type and amount of work carried out. The primary energy content of electricity is 7.3 MJ/kWh. This is based on electricity generation in 2004 of 291 PJ and consumption of 143 PJ [4]. Sixty four percent of electricity generation was from renewable sources [4] and has been included.

Table 1. Energy Values of Direct Fuel Inputs

Fuel	Energy Units	$\text{Energy}_{\text{consumer}}$	Fugitive Multiplier	$\text{Energy}_{\text{primary}}$
Diesel	MJ/ℓ	36.1 [4]	1.23 [3]	44.3
Petrol	MJ/ℓ	32.5 [4]	1.23 [3]	40.0
Electricity	MJ/kWh	3.6	2.04	7.3

3.3.2 Fertiliser, agrichemicals and purchased feed

Fertilisers were broken down into their different nutrient components, based on the findings of Wells [3], to calculate total energy cost. The embodied energy of agrichemicals ranges between 210 to 310 MJ/kg of active ingredient and was adapted from Pimentel [5]. Purchased feed included grain at 2,940 MJ/t DM [6], and silage and hay at 1,500 MJ/t DM [3].

3.3.3 Capital

Capital items were not included in the farm survey. However, based on a recent sheep and beef study [7] that found capital was 9% of total energy, the energy embodied in capital items was accounted for by adding 10% to the on-farm energy inputs, making the final result 9% of total energy use.

3.4 Transport

Road cartage is 0.069 ℓ/tonne-km [6] (3.1 MJ/ tonne-km). Total sea transport was calculated based on the shipping of wool tops from a South Island port to Shanghai China, a distance of 5,650 nautical miles or 10,460 km (www.chinaports.com.cn). A review of shipping fuel use [8], found that energy coefficients for sea transport did show general consistency with one or two exceptions. The figure used in this study is 0.12 MJ/tonne-km.

3.5 Wool Processing

Wool processing includes the early stage processes of sorting and blending, scouring and top making.

The wool processing data is the area with which the least confidence is associated, due to the difficulty of finding suitable literature and industry data. It is also understood that there is considerable variation in energy use between different processing plants.

The clean wool weight, which represents the weight of fibre after grease, suint and dirt has been removed through scouring [9], is 66% of the 'greasy wool weight', although some references report slightly higher yields of 70% [10]. The yield of clean dry fibre in greasy wool, which goes from the wool scourer into the top making stage, is 55% (66% minus 11% water). Inputs in wool scouring were allocated to the two economic outputs on the basis of weight, being 90% to wool and 10% to grease.

The two economic outputs of top making are wool top and wool noils. The allocation of inputs based on mass is wool top 93%, and wool noils 7%.

4 Results

4.1 Farm Description

The three farm categories, extensive, medium intensive and intensive are strikingly different in all aspects of their operations and cover the range of merino sheep and beef farms. Table 2 provides a general description of the farms.

Table 2. Average Farm Area

Farm Category	Average effective area (ha)	Average stock units per hectare	Wool sales (kg/s.s.u.†)	Percentage of wool sales by weight	Percentage of wool sales by revenue
Extensive	14,023	0.9	5.0	30%	-
Medium Intensive	7,422	2.6	5.1	26%	-
Intensive	850	7.4	6.7	24%	-
Survey Average	**7,432**	**3.7**	**5.6**	**27%**	**-**
MAF Merino Model	6,500	1.4	4.9	-	53%

† One sheep stock unit (s.s.u.) is equal to one breeding ewe that weighs 55 kg and bears one lamb

4.2 Resource Inventory

The inventory of resource inputs for the 24 merino farms surveyed is shown in Table 3.

In other agricultural resource input inventories fertiliser is commonly the most significant on-farm energy input. However in this case liquid fuels are slightly higher at 40% of the total on-farm energy cost, followed closely by fertiliser at 39%. Unlike many other agricultural systems where nitrogen dominates, with its high use and high embodied energy cost to manufacture, on merino farms there is largely an even split of embodied energy between nitrogen, phosphorus and sulphur. The exception to this is the intensive operations that show the nitrogen domination more typical of other agricultural systems.

Table 3. Average Resource Inputs and Production

	Unit	per hectare	per s.u.	per tonne greasy wool	per tonne wool top
Direct Energy Inputs					
Diesel	ℓ	2.7	0.8	52	87
Petrol	ℓ	1.0	0.3	18	31
Contractors (diesel)	ℓ	3.2	0.8	52	88
Electricity	kWh	24.7	4.7	286	480
Indirect Energy Inputs (Consumables)					
Nitrogen	kg N	2.1	0.6	30	51
Phosphorous	kg P	4.4	1.4	102	171
Potassium	kg K	0.1	0.0	1	2
Sulphur	kg S	10.6	3.7	271	455
Magnesium	kg Mg	0.1	0.0	1	2
Limestone	kg	44.8	11.2	614	1,033
All Fertiliser	*kg*	*62.1*	*16.9*	*1,020*	*1,714*
Agrichemicals	kg ai	0.08	0.02	2	3
Purchased Feed	kg DM	9.1	2.5	168	283
Production					
Total Farm Production †	kg	66.6	15.3	-	-
Wool	kg	15.0	3.9‡	-	-
Carry Capacity	s.u.	3.7	-	-	-

ai = active ingredient, DM = dry matter
† Total Production includes the sale of meat carcass, cash crops and wool
‡ Production of wool per sheep stock unit was 5.6 kg

4.3 Total Energy Use

4.3.1 On-Farm

Farm energy use was not significantly different across the three farm categories at the 5% level of confidence. Average total energy use for all farms was 24,915 MJ/t dry wool top (economic allocation = 53,390 MJ/t dry wool top), with the 95% confidence interval being ± 4,350 MJ/t (eco. allocation = ± 11,845 MJ/t) and the individual farms ranged between 11,155 MJ/t (eco. allocation = 22,955 MJ/t) and 64,210 MJ/t (eco. allocation = 162,905 MJ/t). Median energy use was 22,595 MJ/t (eco. allocation = 45,935 MJ/t), as outlined below in Table 4 and Figure 2.

Table 4. Total On-Farm Energy Use by Farm Category (MJ)

Farm Category	per hectare	per s.u.	Weight allocation		Economic allocation
			Per tonne greasy wool	per tonne dry wool top	per tonne dry wool top
Extensive	160	170	13,100	22,015	42,240
Medium Intensive	565	225	15,445	25,950	53,395
Intensive	1,940	300	15,940	26,780	64,530
Average	**890**	**230**	**14,830**	**24,915**	**53,390**

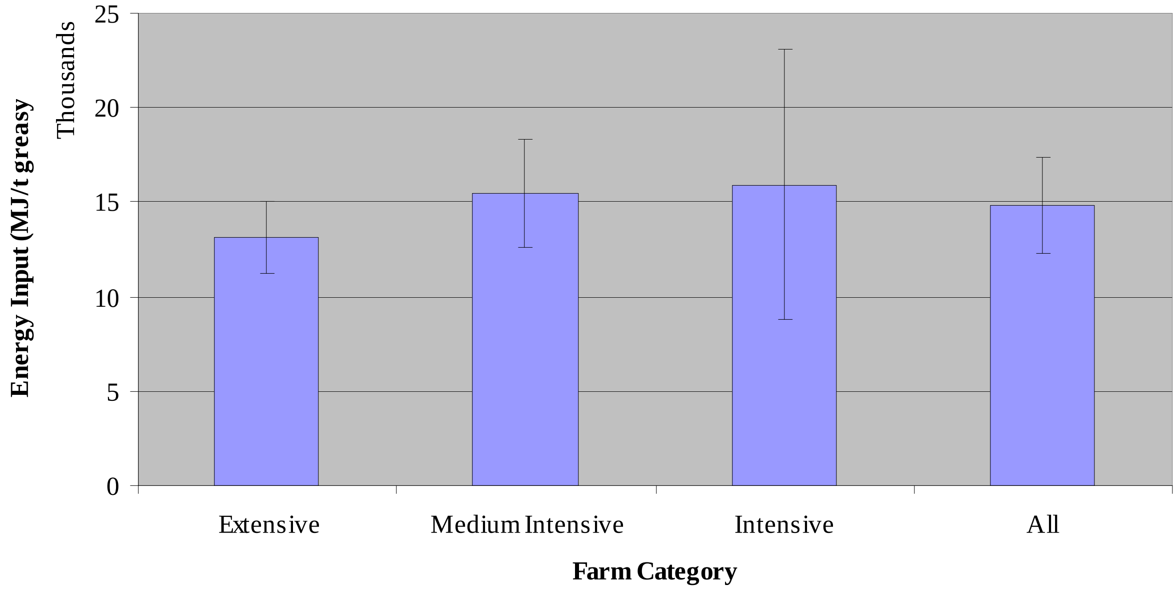

Figure 2. On-Farm Total Energy Input per Tonne Greasy Wool

4.3.2 Processing and Transport

Wool scouring product flows and detergent use came from the literature [9]. Total processing energy use was based on a German wool scouring and top making plant [11]. The energy split between scouring and top making was made using the data from one New Zealand top making operation [12].

The capital in processing was assumed to be negligible due to the large volume of fibre processed during the plants life.

Table 5 summarises the resource inputs in wool processing.

Table 5. Resource Inputs into Wool Processing

	Wool output (kg/t greasy)	By -products (kg/t greasy)	Energy		Detergents	
			(MJ/t greasy)	(MJ/t dry wool top)	(kg ai/t greasy)	(kg ai/t dry wool top)
Wool scouring	550	59	9,590	19,140	13	21
Top making	501	36	1,280	2,560	-	-
Total processing	**501**	**95**	**10,870**	**21,700**	**13**	**21**

Transport included moving greasy wool from the farm to port and shipping the processed wool top from the port of Dunedin to Shanghai China.

Average diesel use for the transport of greasy wool between farm and port was 3.7 ℓ/t greasy wool (6.1 ℓ/t wool top). The shipping of processed wool 5,650 nautical miles to China uses 27.3 ℓ/t wool top. Total energy used to transport wool between the farm and port is 275 MJ/t top and a further 1,210 MJ/t top is used for shipping.

4.3.3 Life Cycle

Table 6 and Figure 3 illustrates the average energy used by the 24 merino farms surveyed on an energy intensity and productivity basis, plus processing energy use through to wool top landed in China.

Table 6. Total Energy Use

	Total Energy Input (MJ)			
	per hectare	**per s.u.**	**per tonne greasy wool**	**per tonne dry wool top**
Direct Energy Inputs				
Diesel	118.7	34.8	2,295	3,855
Petrol	40.3	11.6	730	1,225
Contractors (diesel)	140.9	35.0	2,310	3,880
Electricity	181.6	34.3	2,095	3,525
Sub-total	**481.5**	**115.7**	**7,430**	**12,485**
Indirect Energy Use				
Nitrogen (N)	134.1	36.1	1,955	3,285
Phosphorous (P)	65.4	21.1	1,530	2,570
Potassium (K)	0.8	0.2	15	25
Sulphur (S)	53.2	18.6	1,355	2,275
Magnesium (Mg)	0.5	0.1	5	10
Limestone	26.9	6.7	370	620
All Fertiliser	*280.8*	*82.8*	*5,225*	*8,785*
Agrichemicals	23.4	7.0	445	745
Purchased Feed	22.2	5.6	375	635
Sub-total	**326.4**	**95.3**	**6,050**	**10,165**
Capital Energy Use†	**80.8**	**21.1**	**1,350**	**2,265**
TOTAL ON-FARM	**888.7**	**232.1**	**14,830**	**24,915**
Processing Through to Wool Top				
Cartage to Port				275
Processing Energy				21,700
Detergents				5
Shipping to China				1,210
TOTAL PROCESSING & TRANSPORT				**23,190**
TOTAL				**48,105**

† Estimated at 10% of direct and indirect inputs (9% overall).

The energy profile of dry New Zealand merino wool top landed in China is 48.1 MJ/kg dry wool top.

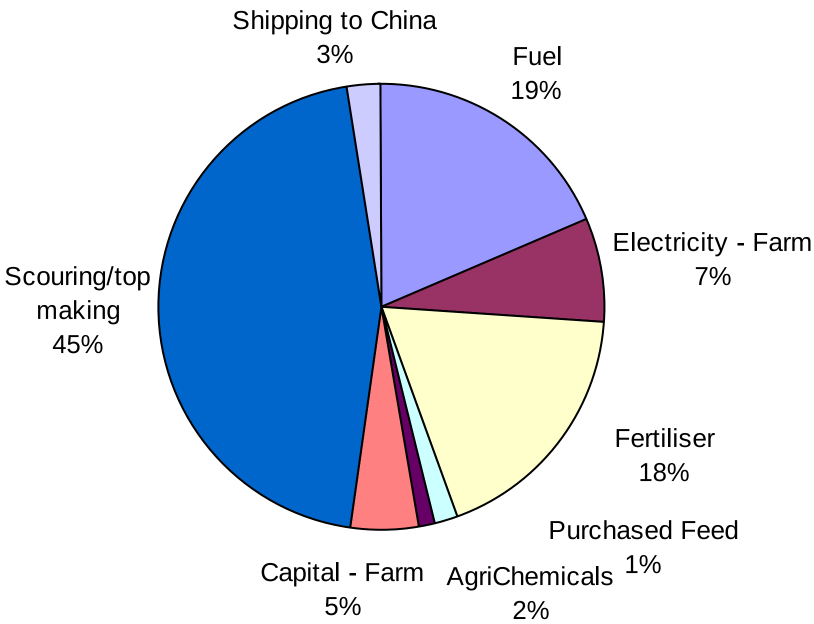

Figure 2. Proportion of Wool Total Energy

4.4 Other Textile Total Energy Use

A comprehensive literature review of energy use for a range of textile fibres was completed. A summary of the findings and the literature that these were adapted from are presented in Table 7.

Table 7. Textile Fibre Energy Use

Textile	Energy consumption † (MJ/kg fibre)	References
Nylon	250	[13, 14, 15, 16]
Acrylic	175	[13, 16, 17]
Polyester	125	[13, 14, 16, 18, 19]
Polypropylene	115	[13]
Viscose	100	[13, 17, 20, 21]
Cotton	55	[13, 17, 19, 22]
Wool	63	[11, 13, 14, 17, 23]‡

† The figures have been adapted from several sources

‡ This project determined an energy wool value of 48 MJ/kg dry wool top and approximately 52 MJ/kg spun wool fibre.

The final stage that wool has been taken through to is dry wool top. It still then requires spinning and winding to transform it into a yarn that would make it comparable with the other fibres. However this was not included due to a lack of suitable data, the closest being cotton spinning and winding that Hammond [24] determined ranged between 3.7 to 14.9 MJ/kg yarn. While wool does not include spinning it also has not taken into account moisture regain from the environment after drying, which would have the effect of lowering the energy footprint by approximately 10%. Taking spinning and wool hydration into account results in spun wool having a total energy consumption of approximately 52 MJ/kg spun wool.

5 Conclusions

Life Cycle Assessments (LCA) have become an important tool for measuring the impact that a product has on the environment, from the extraction of raw materials, through the production process and final product use, disposal or recycling. This study involved a literature review of textile LCAs and conducted a simplified LCA of New Zealand merino wool to determine total energy use from on-farm production of wool through to the delivery of processed wool tops to a spinning mill in China.

The energy intensity of merino farming in New Zealand varies considerably between 160 MJ/ha for extensive grazing farms (0.9 s.u./ha) through to 1,940 MJ/ha for intensive farms (7.4 s.u./ha). Energy productivity was much more consistent across the farm types with merino wool production having a total on-farm energy use of 25 MJ/kg dry wool tops, varying between 22 MJ/kg dry top and 27 MJ/kg dry top for the extensive and intensive farms respectively.

On-farm production accounts for 52% of the total energy required to produce wool top landed at a Chinese spinning mill (25 MJ/kg dry tops); while wool processing adds a further 22 MJ/kg tops (45%) of which almost 90% occurs during wool scouring. Transport is only 3% of total energy use at just 1.5 MJ/kg dry top. The very small transport component adds further weight to Saunders et. al. (2006) [8] conclusions about the inappropriateness of using "Food Miles" as a measure of environmental damage. The allocation methodology makes a significant difference to the on-farm results. Mass was used in this study as the only consistent physical property of all the economic farm outputs and is not subject to swings in farm profitability and world markets. Economic allocation has been used in other studies [7] where the weight of cash crops disproportionately dominates all other farm outputs. Applying an economic allocation methodology to the model in this study increases total on-farm energy productivity from 25 MJ/kg dry top to 53 MJ/kg dry top. While it was not possible to estimate the effect of an economic allocation on the processing result, by weight scoured wool and wool top was 90% and 93% of the economic outputs from their respective processes. It is therefore unlikely that an economic allocation would significantly affect these results. Wool top's total energy use from farm to spinning mill in China is 48 MJ/kg, or if based on an economic allocation model 77 MJ/kg.

The on-farm energy use profile highlights several areas where the industry should place emphasis for improving the overall environmental profile of wool. Fuel use (diesel) was the single largest contributor. Further investigation is needed to show how this fuel is being used; however in other industries tractor driver education and awareness have been shown to improve fuel use by 15%, particularly for draught operations. Reduced and no-tillage cultivation can achieve fuel savings of between 40 to 75% compared to conventional cultivation, and although reduced tillage is common on high country properties, further use of these techniques could be investigated. Fertiliser is the second largest input, so improved fertiliser use efficiency offers opportunities to improve both the energy profile but also significantly improve other environmental impacts like eutrophication and greenhouse gas emissions. For example the increased use of nutrient budgets by farmers is being partially credited with a 13% drop in total New Zealand fertiliser sale volumes between 2004/05 and 2005/06, the largest decrease since subsidies were removed in the 1980's [25].

It was found that wool production uses significantly less energy than comparable man-made fibres, with wool consuming 38% of the energy and resources need to manufacture polyester, 27% of acrylic and just 19% of the energy need to manufacture nylon to the fibre stage. It is important to note that this project focused on establishing merino wools resource and total energy use, and that to build the full environmental profile of wool other environmental impacts such as greenhouse gas emissions, acidification, eutrophication etc need to be added.

This project has provided a significant advance in the understanding of resource inputs in New Zealand sheep and beef farms and in particular the total energy use for the production of merino wool. The second stage of this project is currently being conducted to determine the weighted average energy use for New Zealand wool; which includes all wool types from fine merino to coarse crossbred and a wider range of production systems, from intensive low land properties to extensive high country. This second stage is also placing more emphasis on wool processing and is extending the life cycle analysis into woollen product manufacture.

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