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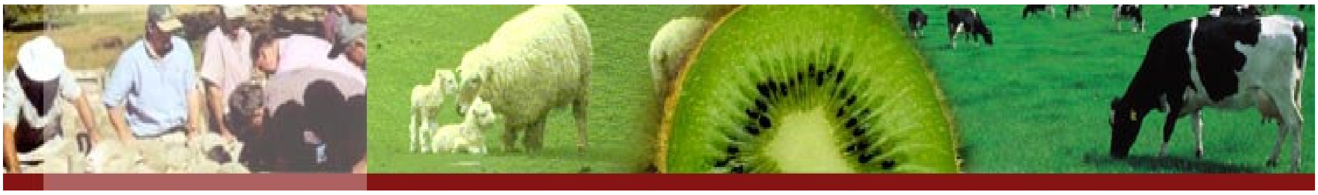

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Total Energy Indicators:

Benchmarking Organic, Integrated and Conventional Sheep and Beef Farms

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The AgriBusiness Group

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List of Abbreviations

Energy and Power

J	joule	basic unit of energy	Factor
kJ	kilojoule	1,000 joules	E3
MJ	megajoule	1,000,000 joules	E6
GJ	gigajoule	1,000,000,000 joules	E9
TJ	terajoule	1,000,000,000,000 joules	E12
PJ	petajoule	1,000,000,000,000,000 joules	E15

W	watt	basic unit of power = 1 joule per second
kW	kilowatt	1,000 watts
kWh	kilowatt-hour	3.6 MJ

Others

ha	hectare	10,000 square metres
kg	kilogram	
t	tonne	1,000 kg
ℓ	litre	
ai	active ingredient	
DM	dry matter	
s.u.	stock unit	
s.s.u.	sheep stock unit	

IFOAM	International Federation of Organic Agriculture Movements
MAF	Ministry of Agriculture and Forestry
MED	Ministry of Economic Development

Conversions

1 ha = 2.47 acres
1 ℓ petrol = 0.90 ℓ diesel (diesel equivalents on an energy basis)
1 kJ = 239 calories
1 kW = 1.34 horse-power (HP)
1 MJ (primary energy) = 0.023 ℓ of diesel
1 MJ (consumer energy) = 0.028 ℓ of diesel

Executive Summary

This projected established a set of benchmark total energy indicators for three sheep and beef and mixed cropping management systems; organic, integrated and conventional. Thirty six farms were surveyed, 12 per management system, as part of the ARGOS programme. ARGOS is a long term programme established to test the null hypothesis, that there is no measurable difference in the economic, environmental and social variables on the three different farming practices.

A detailed resource inventory has been developed of each farming system. This was used to determine a set of energy intensity indicators; per hectare, per stock unit, and per dollar of gross farm revenue; and energy productivity indicators; per tonne of greasy wool, and tonne of sheep carcass weight.

Total energy is the sum of consumer energy (the energy used by the final consumer e.g. what is available to an engine or measured at the electricity meter) plus all the energy used or lost in the process of transforming energy into other forms and bringing that energy or product to the final consumer. Energy use was measured to the farm gate and included fuel and electricity plus the embodied energy in fertiliser, agrichemicals, purchased feed and capital items.

The ARGOS farms had an average effective area of 370 ha, organic farms were on average smaller (336 ha) and integrated were the largest (433 ha). The integrated and conventional farms had a stocking rate of 11.4 s.u./ha while organic farms had on average 8.5 s.u./ha. Wool production was similar, although lowest on the conventional farms. The farms were generating average revenues of $950/ha on the organic farms and $1,060/ha and $840/ha on the integrated and conventional farms respectively.

None of the farm management systems have significantly different total energy intensities, per hectare, per stock unit or per dollar of revenue. The average organic farm had the lowest energy intensity, with the integrated and conventional farms being on average 63% and 30% higher across the three energy intensity indicators (per hectare, per stock unit and per dollar). The average energy intensity per stock unit for the organic farms was 420 MJ/s.u, with a 95% confidence interval of ± 190, integrated farms were 530 MJ/s.u. ± 270, and conventional farms were 450 MJ/s.u. ± 270. Removing a cluster that had high inputs and outputs reduced the energy intensity per stock unit to 370 MJ/s.u. (13% reduction), 410 MJ/s.u. (23% reduction) and 340 MJ/s.u. (23% reduction) respectively.

The embodied energy content of wool was calculated based on an allocation of 11% - 12% of total farm energy; the allocation is determined by wools share of farm revenue. While none of the farming systems were significantly different organic had the best (lowest) energy productivity at 11,170 MJ/tonne wool (± 3,860), integrated was 15,680 MJ/t wool (± 3,680) and conventional was 15,780 MJ/t wool (± 5,830). The only energy indicator that organic farms performed worse than the other management systems on was energy productivity per tonne of sheep carcass weight (CW). Organic farms low energy intensity was not enough to overcome their low sheep sales which averaged 10.9 kg sheep carcass weigh per sheep stock unit (± 2.0), compared to 17.8 kg sheep CW/s.s.u. (± 6.1), and 15.5 kg sheep CW/s.s.u. (± 4.2) on integrated and conventional farms respectively. The resulting energy productivity indicators are 16,000 MJ/tonne sheep CW (± 5,010), 15,600 MJ/t sheep CW (± 4,270), and 11,300 MJ/t sheep CW (± 4,410) for the organic, integrated and conventional farms respectively. The median values showed the same trend, although they were 13%, 6% and 8% lower respectively.

The only indicator that was consistently statistically significantly different (at the 5% level) between the farm management systems was indirect energy use, which is dominated by the influence of inorganic nitrogen fertiliser applications of which organic farms do not apply any.

This project has established a set of benchmark total energy indicators. Confidence in the results will be strengthened by additional sampling in subsequent years. Further study and linkages with other disciplines is needed to answer the question as to whether these indicators are sustainable. Of particular interest would be the relationship between fertiliser inputs and soil nutrient and biology monitoring. Is the low energy footprint of the organic indirect energy inputs, predominantly caused by no inorganic nitrogen, utilising reserves established by previous management practices or is it sustainable in its own right?

Based on these benchmarks the next step should be to conduct sensitivity analysis and identify environmental hotspots with the objective of determining where management should concentrate when investigating ways to improve their overall environmental performance.

Due to the detailed inventory of resource use and energy flows that have been developed in this study expanding the number of impact categories and the system boundary will enable a life cycle assessment (LCA) study to be conducted. More importantly ARGOS, with its multi disciplinary approach, has the potential to link the indicators, which show potential environmental impacts, with actual impacts. Three impacts to target would be eutrophication (nutrient enrichment of ecosystems) both because of the ability to measure loss (nitrogen leaching), the impact (enhanced biomass production in waterways) and the stark contrasting differences in fertiliser use between the management systems. The other impact categories to target would be greenhouse gas emissions, part of which are linked to nitrogen fertiliser use and production intensity, and eco-toxicity, which is linked to pesticide use.

1. Introduction

1.1 Agriculture Research Group on Sustainability (ARGOS)

ARGOS is a transdisciplinary research project involving economists, sociologists, farm management experts and ecologists to assess the sustainability and socio-ecological resilience of farms and orchards participating in organic, integrated management, conventional, and Māori farming systems. The overall objective is to move New Zealand primary production to a new level of innovation by providing evidence of the economic, environment and social effects of different farming systems, and by focusing attention on farmers as innovators. Enhanced pathways to sustainability will benefit New Zealand via improved export performance, greater innovation by both farmers and scientists and improved environmental performance.

The project is funded by the Foundation for Research and Technology (FRST) and is a joint venture between The Agribusiness Group, Lincoln University, and the University of Otago. In order to truly achieve the projects objectives plans have been developed to run the project over a 20 to 30 year time scale. Currently the first six years of funding has been secured.

A major part of the ARGOS programme is testing the null hypothesis that there are no measurable differences in the economic, environmental and social consequences of different farming practices in a number of agricultural sectors. The three main production sheep and beef production systems being studied are:

- Conventional
- Integrated
- Organic

Conventional farms use contemporary land management practices and are established as the control group. The two alternative management strategies are integrated and organic. The term organic will be used to indicate 'certified organic'. New Zealand's organic certification standards are closely aligned to the wider guidelines of the world organic body IFOAM. 'Integrated' is used to indicate systems of Integrated Pest or Crop Management used to reduce or eliminate pesticides, increase the presence of beneficial pest predators, and encourage environmentally responsible soil, water and energy management on farms (Campbell et al., 2004). These farms tend to be much more product specification focused.

This energy study compiles an inventory of resource flows for 36 sheep and beef farms participating in the ARGOS programme, and establishes a set of total energy indicators for the three management systems organic, integrated and conventional farming. It forms part of Objective 3 - Farm Production and Economic Analysis, lead by Professor Caroline Saunders[1]. This objective will determine the effect of the management system on farm production and financial performance. This will be achieved by comparing a range of performance data from the treatment and control farms, comparing this performance with industry averages, and testing for significant differences between the treatment and control. Once the benchmarks have been established subsequent years will assess the reliability of the data, as well as focusing on trade effects. Results will show how farmers can best achieve sustainable production targets. Outputs from this objective will also contribute to syntheses across all objectives so that farmers and their sector representatives can identify the best pathways to achieve sustainability.

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1.2 Total Energy Analysis

1.2.1 Description

Total energy analysis is the sum of all energy inputs such as electricity and fuel, plus all the energy used or lost in the process of delivering energy to the consumer, plus all the energy embodied in consumables such as fertiliser and that embodied in capital items. In this research, the consumers are the ARGOS farms.

Total energy analysis first involves establishing the system boundary and then identifying and quantifying the mass and energy flows across and within that system boundary. This is presented as a detailed inventory.

All inputs are allocated primary energy values. This is the energy involved in extracting, manufacturing, transforming and delivering all resources used within the system.

A set of total energy intensity indicators are determined on the basis of effective farming area, stock units and revenue. Productivity indicators can also be determined by incorporating farm outputs such as the weight of wool and stock sales.

Total energy analysis has progressed on to life cycle assessment (LCA) where a product or service's environmental footprint is determined. These studies have become vital to support the development of eco-labelling schemes and to quantify environmental claims.

1.2.2 Previous Studies

There has only been a small number of energy studies conducted on sheep and beef farms. The most recent of which was for the NZ merino industry (Barber and Pellow, 2006). This study included all on-farm inputs plus processing wool through to wool top landed in China. The average total energy intensity was 800 MJ/ha and 210 MJ/s.u. The intensive merino farms (7.4 s.u./ha) had an energy intensity of 1,750 MJ/ha and 270 MJ/s.u. Most of the 24 surveyed farms only had animal production (meat and wool), with just three farms also growing crops as part of their production system.

Barber and Pellow (2006) found that a kilogram of greasy wool had an energy value of 13 MJ/kg. This energy productivity indicator was developed using a mass based allocation methodology rather than the economic allocation used in this study.

Nguyen and Haynes (1995) compared the energy efficiency of three pairs of conventional and alternative mixed cropping (pasture and arable) farms in Canterbury. They found that energy intensity was considerably lower under alternative (organic or biodynamic) than conventional sheep meat production at two sites and similar at a third. The annual energy intensity per hectare for conventional animal production (meat and wool) was 1,010 MJ/ha (750 – 1,210 MJ/ha) and 500 MJ/ha (88 – 1,094 MJ/ha) under the alternative management systems.

Earlier studies (Nguyen et al., 1992) found that soil nutrient reserves were being rapidly depleted at the biodynamic site where reserves had been built up when the farm was under conventional management. This highlights the importance of longitudinal studies as it could be argued that two of the three sites had unaccounted inputs from previous fertiliser applications. The alternative farm with the energy intensity equivalent to the conventional system was maintaining soil fertility by the application of elemental sulphur and reactive phosphate rock.

Smith and McChesney (1979) found the national average for sheep and beef farms (meat and wool only) was 1,300 MJ/ha. High country South Island farms were as low as 100 MJ/ha, South Island Fattening breeding (class 6), Intensive fattening (class 7) and mixed cropping (class 8) were 2,200, 3,800 and 4,700 MJ/ha respectively.

2. Methodology

2.1 System Boundary

The system boundary is to the farm gate. This includes the extraction, refinement, transmission losses, formulation, packaging and transport to the farm of:

- fuel;
- electricity;
- fertiliser;
- agrichemicals;
- purchased feed and
- capital equipment.

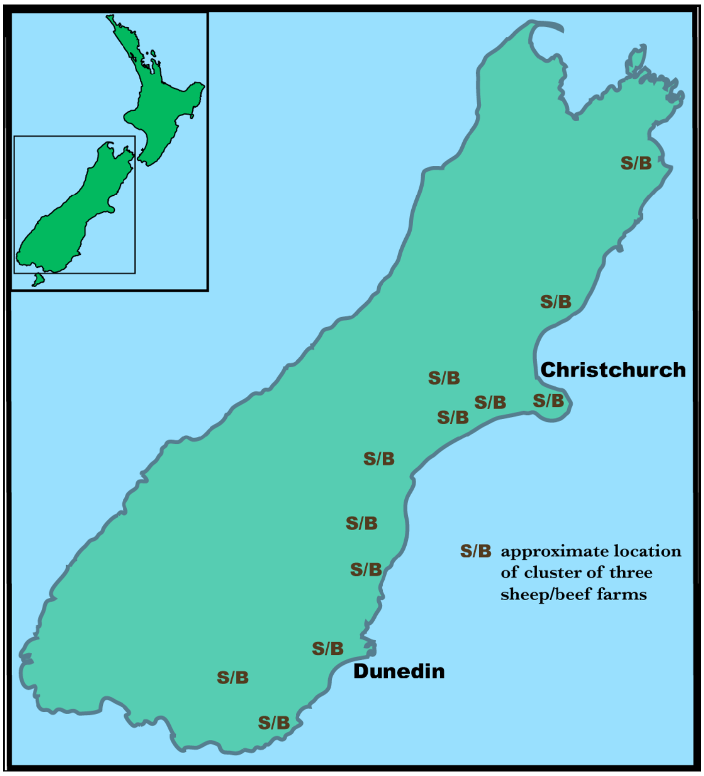
2.2 Farm Description

There are 36 sheep and beef farms in the project. These are split into 12 clusters with an organic, integrated and conventionally managed farm in each cluster. The farms within each cluster are in close proximity. One cluster does not have a conventional farm at this stage while another cluster has four farms with the additional farm converting to organics; this farm has not been included in the analysis.

One integrated farm was excluded due to insufficient information being available. One conventional farm was partially excluded due to insufficient fuel data, their indirect energy inputs (fertiliser, agrichemical and purchased feed) and capital inputs were included.

The geographical spread of the clusters is illustrated in Figure 1 (Lucock, 2005).

Figure 1. Geographic spread of sheep/beef farm clusters in ARGOS



2.2.1 Farm Management

The organic farms are all ‘certified organic’. New Zealand’s organic certification standards are closely aligned to the wider guidelines of the world organic body IFOAM.

The integrated farms use integrated pest or crop management (IPM) to reduce or eliminate pesticides, increase the presence of beneficial pest predators, and encourage environmentally responsible soil, water and energy management (Campbell et al., 2004).

Conventional farms use contemporary land management practices, which in New Zealand revolves around all year round outdoor pastoral farming systems.

2.2.2 Farm Revenue

Detailed farm budgets were prepared for all the farms as part of the overall ARGOS programme. The revenue component of these budgets was used to allocate energy use amongst the different product streams, see Section 2.4 Allocation.

Total revenue was the sum of sheep, wool, cattle, deer, and crop sales plus grazing income. This is slightly different to the full economic analysis which includes sundry income, which can include contracting services, rate rebates, rent and other miscellaneous items as part of total farm revenue.

Farm revenue was also used as a check against the number of stock and weight of wool sold. Where there was either a data gap or clearly a wrong figure provided in the farmer survey the revenue figure was used together with average prices to estimate the weight of wool or number of stock sold. Average wool, sheep and cattle prices were determined for each management system. On one farm where a budget had not been completed the weight of wool sold and stock sales were used to estimate the revenue streams from the average prices.

2.2.3 Stocking Rate

Livestock in New Zealand are commonly given a ‘stock unit’ (s.u.) value. The basic unit (one stock unit) is one breeding ewe that weighs 55 kg and bears one lamb. This ewe consumes approximately 550 kilograms of dry matter per year. Other livestock are measured against this standard, for example, a cow commonly has a value of 6 stock units. In other words they consume approximately six times the amount of feed as a ‘standard’ ewe over a year (Fleming, 2003).

The number of each stock class wintered was collected from the farmers, together with stock purchases and sales.

Stock class and stock unit values are presented in Table 1.

Table 1 Stock Units

Stock Class	Stock Unit		Stock Class	Stock Unit
Sheep			**Deer**	
Ewes	1.0		Hinds	1.9
Wethers	0.7		Rising 1 year deer	1.8
Hoggets	1.0		Stags	2.8
Beef Cattle			Weaners	1.3
Cows	6.0			
Rising 1 year heifers	3.5			
Rising 1 year steers	4.0			
Rising 2 year heifers	4.5			
Rising 2 year steers	5.0			
Bulls	6.0			

Source: Fleming, 2003. Farm Technical Manual

2.2.4 Stock Sales

The number of animals sold was collected in the farmer survey. Stock purchases were not collected, although these were only minor with just two farms having a large number of stock purchases; they will be included in the next survey.

When available the individual farms average carcass weight of prime lamb sales was collected along with ewe mating weights. Store lamb weights were not collected so their live weight was assumed to be 10 kilograms less than the prime lamb live weight. Prime lamb sales were 81%, 90% and 81% of all lamb sales for the organic, integrated and conventional farms. Where farm specific weights were not available the average weights for that farms management system was used. Conventional farmed cattle were assumed to be sold at a live weight of 435 kg (Barber and Pellow, 2006) and conventionally farmed deer were sold at 100 kg (De Vos, 1982). The weights for the organic and integrated farms were then adjusted by 97% and 102% of the conventional farm weights. This was found to be the difference in sheep weights between the three management systems. In order to estimate a farm's total carcass weight sales, the number of animals sold was multiplied by either the farms known animal weight or its average management system weight and the dressing out percentage. These weights are shown in Table 2.

In determining a farms total weight output it was assumed that all stock sales were eventually destined for the meat works. While this is not always true, it is in the vast majority of cases.

Lamb and ewes had a dressing out percentage of 42% (AgFact, 1997). Beef was assumed to have a dressing out percentage of 56%, based on the data from steer processed at Manawatu Beef Packers (Charolais, 2005). Deer dressing out percentage was 58%, based on red deer ranging between 51 and 65% (De Vos, 1982).

Table 2 Animal Sale Weights and Dressing Out Percentage

	Animal Live Weight (kg)				
	Prime lamb	Store lamb	Ewe	Beef	Deer
Organic	40	30	67	421	97
Integrated	42	32	72	446	102
Conventional	41	31	70	435	100
Dressing out percentage	42%	42%	42%	55%	58%

2.2.5 Crop Sales

Crop types, the area grown, and their harvested weight were collected in the farmer survey, although there are some data gaps that meant we were unable to describe the cropping area sufficiently well.

2.2.6 Wool Sales

All farms reported their total greasy wool sales in tonnes.

2.3 Total Energy Use

Total energy use is calculated using primary energy values. This is the sum of consumer energy plus all the energy used or lost in the process of transforming energy into other forms and in bringing the energy or product to the final consumers. Consumer energy is defined as the amount of energy consumed by the final user, for example the kilowatt-hours recorded on the electricity meter or the actual energy value of fuel available to an engine.

When calculating total energy use it is necessary to use primary energy, so that direct, indirect and capital energy sources are being accounted for on the same basis.

2.3.1 Farm Direct Energy Inputs

2.3.1.1 Diesel

The gross energy content or consumer energy of diesel is 36.1 MJ/ℓ (MED, 2005). The primary energy content, which includes an allowance for the fuel's production and delivery, adds an extra 23% (Wells, 2001). This makes the total primary energy content of diesel 44.3 MJ/ℓ. These figures are summarised in Table 3.

On-farm fuel use, which included fuel used by vehicles on the road, was recorded as either litres or dollars. The dollar figure was converted into litres assuming an average diesel price of $0.64/ℓ (the average price excluding GST in 2003/04). Personal fuel use was subtracted based on either the distance travelled or dollars spent.

The quantity of lubricants used was not collected, as it was considered insignificant.

2.3.1.2 Electricity

Where possible electricity use was recorded based on the meter readings from two accounts that were 12 months apart. Where this was not possible electricity use was estimated from the dollars spent. Estimating electricity use this way is difficult and considerably less accurate due to different per unit rates and fixed line rentals, particularly on those farms that irrigate.

Based on the nine farms (2 irrigated) that did supply their accounts it was found that the average general line rental was $1.22/day and the average unit rate was $0.112/kWh. For the irrigated properties without meter readings electricity use was based on a fixed line charge of $79/irrigated ha and $0.082/kWh.

The consumer energy content of electricity is 3.6 MJ/kWh. However, the primary energy content is much higher at 7.5 MJ/kWh. This is based on the electricity generation in the 12 months to June 2004 (the period that most closely matches the survey period) of 293 PJ and consumption of 142 PJ (MED, 2005). The primary energy content takes into account electricity conversion losses in generation (141 PJ) and transmission losses (11 PJ). It takes 2.07 kWh of primary energy to supply 1 kWh to the consumer. This is an improvement on what Wells (2001) reported of 8.2 MJ/kWh (2.27 primary to consumer energy) based on 1997 data and Barber (2004) of 8.1 MJ/kWh based on 2002 data. The 2004 figure is shown in Table 3 below.

New Zealand has well established renewable energy sources, the main two being hydro and geothermal. In 2004 62% of electricity generation came from renewable sources (MED, 2005).

Table 3 Energy Values of Direct Fuel Inputs

Fuel	**Energy Units**	**Energy $_{consumer}$**	**Fugitive Multiplier**	**Energy $_{primary}$**
Diesel	MJ/ℓ	36.1 [a]	1.23 [b]	44.3
Electricity	MJ/kWh	3.6	2.07	7.5

Data sources:

[a] NZ Energy Data File 2005 (MED)

[b] Wells, 2001

2.3.1.3 Fuel Use by Contractors

Fuel use by contractors was calculated from the type and amount of work that they carried out.

Fuel consumption data has been developed by McChesney (1981) and CAE (1996) for various agricultural activities and the adapted results were presented by Wells (2001). Adaptations in this study to the Well's figures include a single per hectare fuel cost for conventional cultivation of arable type crops of 80 ℓ/ha (Barber, 2004) and direct drilling at 20 ℓ/ha, based on savings of 80% compared to conventional cultivation (Barber and Pellow, 2005). Wells reported aerial topdressing at 7 ℓ/ha, which appears to be very high. This study uses a rate of 1.1 ℓ/ha of aviation fuel (Sinclair pers. comm., 2005). Fuel use for road transport was estimated at 0.069 ℓ/tonne-km. This was based on monitoring the fuel use by several trucks over a six month period and is similar to the figure used by Wells (2001) of 0.079 ℓ/tonne-km.

Table 4 Average Diesel Consumption Rates for Agricultural Operations

Activity	Fuel Use	Activity	Fuel Use
Ploughing	18 ℓ/ha	Hay pickup	1 ℓ/t
Power harrow	8 ℓ/ha	Forage harvesting	2 ℓ/t
Rolling	4 ℓ/ha	Shelter trimming	39 ℓ/hr
Conventional cultivation	80 ℓ/ha	Spraying	10 ℓ/hr
Direct drilling	20 ℓ/ha	Ground fertiliser spreading	3 ℓ/ha
Mowing	6 ℓ/ha	Aerial topdressing	1.1 ℓ/ha
Raking	2 ℓ/ha	Cartage	0.069 ℓ/t-km
Bailing	2 ℓ/t		

2.3.2 Farm Indirect Energy Inputs

2.3.2.1 Fertiliser

To calculate the energy cost of each fertiliser they were broken down into their different nutrient components.

Table 5 shows the average energy costs of manufacturing each component (Wells, 2001). These are average figures taken from a range of different fertiliser production methods.

Table 5 Energy Requirements to Manufacture Fertiliser Components

Component	Energy Use (MJ/kg)
Nitrogen (N)	65
Phosphorus (P)	15
Potassium (K)	10
Sulphur (S)	5
Magnesium (Mg)	5
Limestone	0.6

2.3.2.2 Agrichemicals

The energy requirement to manufacture agrichemicals was adapted from Green (1987) for the different agrichemical categories, and ranged between 97 to 210 MJ/kg of active ingredient (ai). Animal remedies were assumed to have a total energy input of 210 MJ/kg ai, adapted from Wells (1998).

The energy required for formulating the agrichemicals into their final product from the pure active ingredient is dependant on the type of formulation. All product were assumed to be emulsifiable concentrates except fungicides which were wettable powders. These have embodied energy contents per kilogram of agrichemical of 20 and 30 MJ/kg respectively (Green, 1987).

The energy in packaging requires 2 MJ/kg (Green, 1987).

Transport is generally a small energy cost when compared to the total embodied energy in a product. All products were assumed to be manufactured in Australia except for the animal remedies and fungicides which were assumed to be manufactured in Germany. Transport from Australia requires 0.4 MJ/kg and Germany 4.6 MJ/kg. Table 6 shows a summary of the agrichemical energy inputs.

Table 6 Energy Inputs for Various Agrichemicals

Agrichemical	**Manufacture MJ/kg ai**	**Formulation, Packaging and Transport MJ/kg product**	**Total MJ/kg product**
Bloat oil	100	22	72
Animal remedies	210	27	132
Herbicide	203	22	95
Insecticide	97	37	77
Fungicide	185	22	115
Other	100	22	72

2.3.2.3 Purchased Feed

Most farms produced their own silage or hay as supplementary feed. The cost of this is taken into account through the use of inputs such as diesel and fertiliser. Approximately a quarter of the farms also purchase additional feed; either silage, hay or grain. The cost of this purchased feed needs to be accounted for. The embodied energy of these inputs is shown in Table 7.

Barley has a total energy cost of 34,150 MJ/ha (Barber, 2004). Where the grain and straw are harvested the revenue split is approximately 70/30. This is based on $250/t grain and $25 per medium straw bale (320 kg). Based on a yield of 8.8 t/ha of grain and 4.4 t/ha of barley straw (Barber, 2004), the embodied energy in the grain is 2,720 MJ/t and 2,330 MJ/t straw. The average grain and straw dry matter (DM) content is 85% (Wrightson, 2005). This is used to calculate the energy value per tonne of dry matter. Pimentel et al. (1983) found that organic wheat had an energy profile that was 32% less than conventionally grown wheat. While they found a higher energy profile then the NZ grain we have used the same proportional difference. Grain was the only purchased feed recorded for the Organic farms.

Silage has an energy content of 1,500 MJ/t DM (Wells, 2001) and hay, assuming the same energy requirement as silage, is 27 MJ/small bale. A small hay bale was assumed to weigh 21.5 kg and have a dry matter content of 85%.

Table 7 Embodied Energy Content of Purchased Feed

Feed	**MJ/unit**	**units**	**MJ/t DM**
Silage	1,500	tonne dry matter	1,500
Hay	27	small bale	1,500
Barley straw	2,330	tonne	2,740
Grain (barley)	2,720	tonne	3,200
Grain (organic)	1,850	tonne	2,180

2.3.3 Farm Capital Energy Inputs

Capital items have a certain amount of energy embodied in them due to their extraction, manufacture and maintenance, which can be calculated by multiplying the mass of each component by an appropriate energy coefficient.

2.3.3.1 Self Propelled Vehicles and Implements

Table 8 gives the energy associated with machinery. These figures include the embodied energy of the raw materials, construction energy, an allowance for repairs and maintenance, and international freight (Wells, 2001). As Table 8 shows the embodied energy of vehicles and implements used in this report are 65.5 MJ/kg and 51.2 MJ/kg respectively. This is based on a simplification of the approach used by Audsley et al. (1997) and incorporates New Zealand data for steel and rubber. This is lower than the figure reported in Wells (2001) but more akin to that used by Doering (1980) who estimated a value of around 70 MJ/kg.

All vehicles are assumed to contain 95 per cent steel and 5 per cent rubber; while implements are 100 per cent steel (Audsley et al., 1997). In New Zealand the production of steel is 32 MJ/kg and rubber is 110 MJ/kg (Baird et al., 1997). Energy consumption for manufacturing and the percentage attributed to repairs was the average of three machine categories and two implement categories given by Audsley et al. (1997).

Table 8 Energy Used in Manufacture and Maintenance of Machinery

Machinery type	**Energy in Materials (MJ/kg)**	**Energy Consumption for Manufacture (MJ/kg)**	**Energy Consumption for Repairs (%)**	**Total Energy (MJ/kg)**	**Working Life (years)**
Vehicle	35.9	14.0	31.3	65.5	15
Implement	32.0	8.0	28.0	51.2	20

2.3.3.2 Buildings

All buildings including wool sheds, hay barns, and implement sheds had an embodied energy coefficient of 590 MJ/m^2 (Wells, 2001).

2.3.3.3 Races and Fences

The energy embodied in races is 75 MJ/m and were assumed to have a working life of 30 years (Wells, 2001). To estimate the length of races a formula developed by Wells (2001) was used using the average paddock size. As this approach was based on a dairy farm it is likely to be an overestimate, however it is only a very small component of the overall energy use and does not warrant further investigation at this stage.

A formula to estimate the length of fences and the energy embodied in conventional and electric fences was developed by Wells (1998). The energy embodied in deer fencing includes the wire at 30.4 MJ/m, based 87.3 kg/100m and galvanised wire at 34.8 MJ/kg (Baird et al., 1997), plus posts 1.9 MJ/m. This is based on a post spacing of 7m and deer posts being 50% longer than typical post (2.7m compared to 1.8m) which are 9 MJ each (Dawson, 1977). Farmers were asked for the percentage of conventional (seven wire post and batten), electric (three wire), or deer fences.

Table 9 Energy Embodied in Fencing and Working Life

Fence Type	**Total Energy (MJ/m)**	**Working Life (years)**
Conventional	20	25
Electric	4.5	15
Deer	32	25

2.3.3.4 Water Pipes

Farmers were asked for the type, size and length of water pipes. PVC has an embodied energy of 120 MJ/kg and polyethylene is 103 MJ/kg (Baird et al., 1997). The mass of all the different pipes was determined and the total embodied energy calculated. This was then divided by the working life. It was assumed that the life of PVC is 40 years, medium density polyethylene is 30 years and low density polyethylene is 20 years.

2.4 Resource Allocation

Sheep and beef farms in New Zealand are mixed production systems that produce meat, wool and crops. Each product is intertwined and integral to improving the overall productivity of the whole farm. Hence the inputs are aggregated as a total for the farm and are not separately allocated to the individual animal or crop types, even for the few instances where this may be possible. For example, electricity for irrigating crops is still divided over the whole farm production system rather than just allocated to the cropping system. This is because a paddock being grazed may have benefited from having an irrigated crop grown in it the previous year in terms of improved soil structure and fertility.

When it is not possible to avoid allocation, by analysing the system in more detail or using physical causality (by varying the proportions between co-products), allocation of resources needs to be on the basis of physical relationships or economic value.

On a mixed sheep and beef farm mass is the only common physical relationship between the co-products. Other parameters sometimes used to determine physical allocation include food energy value, but in this case that does not accommodate the production of seeds or wool. Even within a single crop the food value varies depending upon whether it is destined for human or animal consumption.

The financial approach is the least desirable due to its susceptibility to variations in price between locations and time. This is particularly relevant in a longitudinal study like this. 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.

Consistent with the ISO 14041:1999 standard where allocation can not be avoided, and the only physical relationship being mass is not suitable due to the large discrepancies caused when comparing a farm that grows a clover seed crop compared to one growing maize silage or no crop at all, economic value is used.

3. Results

The results are presented both as averages with their 95% confidence interval and medians. Medians often give a better feel for the systems and are not influenced by outliers. No detailed statistical analysis, sensitivity analysis, or modelling has been done beyond establishing this set of benchmark indicators and their confidence intervals.

3.1 Farm Physical Description

Tables 10 to 14 are a summary of the three farm management systems. Overall the three systems are being farmed on similar sized platforms. On average the organic farms have the lowest stocking rate, although not significantly less than the average integrated and conventional farms.

Table 10 Farm Area

Farm Category	Number of Farms	Effective Area (ha)	± 95% Confidence Interval	Median
Organic	12	336	± 87	318
Integrated	11	433	± 199	320
Conventional	11	362	± 78	325

Table 11 Farm Stocking Rate

Farm Category	Stock Units/ha	± 95% Confidence Interval	Median
Organic	8.5 †	± 1.9	8.1
Integrated	11.5	± 2.3	10.9
Conventional	11.3	± 2.0	10.9

Table 12 Wool Production Intensity

Farm Category	Number of Farms	Wool (kg/s.s.u.)	± 95% Confidence Interval	Median
Organic	11	4.2	± 0.8	3.9
Integrated	11	4.1	± 0.8	3.7
Conventional	11	3.5	± 0.4	3.5

While the conventional farms have the highest prime lamb production per head (Table 13), significantly higher than the organic farms at the 5% level, the integrated farms with their high lambing percentage results in the highest productivity per sheep stock unit (Table 14). Table 15 shows the total meat sales, including sheep, beef and deer.

Table 13 Sheep Carcass Weight per Head

Farm Category	Prime Lamb Carcass Weight (kg CW/head)	Median	Sample size (n)	Ewe Carcass Weight (kg CW/head)	Median	Sample size (n)
Organic	16.8 [†] ± 0.5	16.7	11	28.1 ± 2.2	27.3	4
Integrated	17.5 ± 0.2	17.4	8	30.7 ± 2.4	30.7	6
Conventional	18.2 ± 0.8	18.1	8	29.3 ± 1.4	29.4	5

[†] Significantly less than the conventional farms at the 5% level.

Lamb carcass weight is the sum of prime lamb and store lamb sales. Prime lamb carcass weights were available for most farms as was the number of lambs sold and the percentage that were sold prime. Store lambs were assumed to be 10 kg live weight per head lighter or based on a 42% dressing out percentage 4.2 kg carcass weight lighter.

Table 14 Sheep Production Intensity

Farm Category	Lamb[†] Carcass Weight (kg CW/s.s.u)	Median	Lambs sold as prime	Sheep[‡] Carcass Weight (kg CW/s.s.u.)	Median	Sample size (n)
Organic	10.9 ± 2.0	9.9	81%	14.5 ± 2.3	13.7	12
Integrated	17.8 ± 6.1	12.5	90%	22.5 ± 6.1	16.3	10
Conventional	15.5 ± 4.2	12.7	81%	19.0 ± 3.9	16.0	10

[†] The sum of prime and store lamb carcass weights divided by total sheep stock units
[‡] Includes both lamb and ewe sales.

Table 15 Total Farm Meat Production

Farm Category	Total Carcass Weight (kg CW/ha)[‡]	Median	Total Carcass Weight (kg CW/s.u.)[‡]	Median
Organic	163 ± 39	185	19.4 ± 2.7	19.9
Integrated	358± 176	255	28.2 ± 6.4	26.4
Conventional	274 ± 87	242	25.2 ± 8.4	20.3

[‡] Includes the sale of lambs, sheep, cattle and deer.

3.2 Farm Economic Description

Total revenue (excluding sundry) per hectare varies widely within each farm management systems. There is considerably less variation on a stock unit basis with the organic farms show the highest returns closely followed by the integrated farms.

Table 16 Revenue

Farm Category	Total Revenue ($/ha)	Animal Revenue ($/s.u.)
Organic	947 ± 474	70 ± 14
Integrated	1,061 ± 501	63 ± 9
Conventional	840 ± 320	54 ± 9

Table 17 describes the revenue streams of the farms. These are used as the basis of allocating resources for the productivity energy indicators.

Table 17 Revenue Streams

Farm Category	Sheep	Wool	Cattle	Deer	Crops	Grazing
Organic	52%	11%	15%	1%	22%	0%
Integrated	55%	13%	17%	0%	13%	2%
Conventional	45%	12%	20%	2%	16%	4%

3.3 Resource Inputs

The inventory of all resource inputs into the farming systems has been presented in Table 18 and 19 on a per hectare and per stock unit basis.

Both tables show that the integrated system being the most resource intensive, particularly electricity and nitrogen. The higher inputs are reflected in the highest animal productivity. It could be expected that these higher inputs are the result of greater cropping but the integrated farms have the lowest share of crop revenue. Two organic farms, 4 integrated and 3 conventional farms are irrigated. The average irrigated area on these 9 farms is 134 ha, 235 ha, and 164 ha for the organic, integrated, and conventional farms respectively.

Table 18 Average Resource Inputs and Production per Hectare

	Unit per Hectare	**Farm Management**		
		Organic	**Integrated**	**Conventional**
Direct Energy Inputs				
Diesel	ℓ	40.3	38.7	47.8
Electricity	kWh	55.6	173.3	73.7
Indirect Energy Inputs (Consumables)				
Nitrogen	kg	0.0	26.1	10.7
Phosphorous	kg	13.0	25.5	21.8
Potassium	kg	0.5	1.8	2.0
Sulphur	kg	1.0	36.6	22.5
Magnesium	kg	1.6	1.9	3.0
Lime	kg	131.2	236.2	63.2
Agrichemicals	kg ai	0.0	2.2	1.2
Purchased Feed	kg DM	0.0	0.2	0.0
Capital Energy Inputs				
Vehicles	kg	2.6	3.2	1.9
Buildings	m^2	0.2	0.1	0.1
Fences	m	5.1	4.8	4.2
Production				
Carry Capacity	s.u.	163.4	326.9	274.1

ai is active ingredient

Table 19 Average Resource Inputs and Production per Stock Unit

	Unit per Stock Unit	Farm Management		
		Organic	Integrated	Conventional
Direct Energy Inputs				
Diesel	ℓ	6.1	3.4	4.8
Electricity	kWh	7.7	15.9	8.3
Indirect Energy Inputs (Consumables)				
Nitrogen	kg	0.0	2.1	1.1
Phosphorous	kg	2.1	2.2	2.2
Potassium	kg	0.1	0.1	0.2
Sulphur	kg	0.1	3.5	2.2
Magnesium	kg	0.2	0.1	0.3
Lime	kg	13.8	22.3	7.1
Agrichemicals	kg ai	0.0	0.2	0.1
Purchased Feed	kg DM	0.0	0.0	0.0
Capital Energy Inputs				
Vehicles	kg	0.4	0.3	0.2
Buildings	m^2	0.0	0.0	0.0
Fences	m	0.7	0.4	0.4

ai is active ingredient

3.4 Total Energy Indicators

3.4.1 Energy Intensity

Energy intensity is measured as the energy input per hectare, per stock unit or per dollar of revenue. None of the farm management systems have significantly different total energy intensities. The average organic farm had the lowest energy intensity, with the integrated and conventional farms being on average 67% and 30% higher across the three energy intensity indicators.

The one aspect that is significantly different is the indirect inputs, which is mainly attributable to no inorganic nitrogen applications on the organic farms compared to 26.1 and 10.7 kgN/ha on the integrated and conventional farms respectively. Those integrated and conventional farms without crops applied 11.1 and 8.3 kgN/ha respectively, see Figure 2.

Direct and capital energy intensities are similar across all farm management systems, particularly once the variation caused by cropping is removed.

Table 20 Energy Intensity

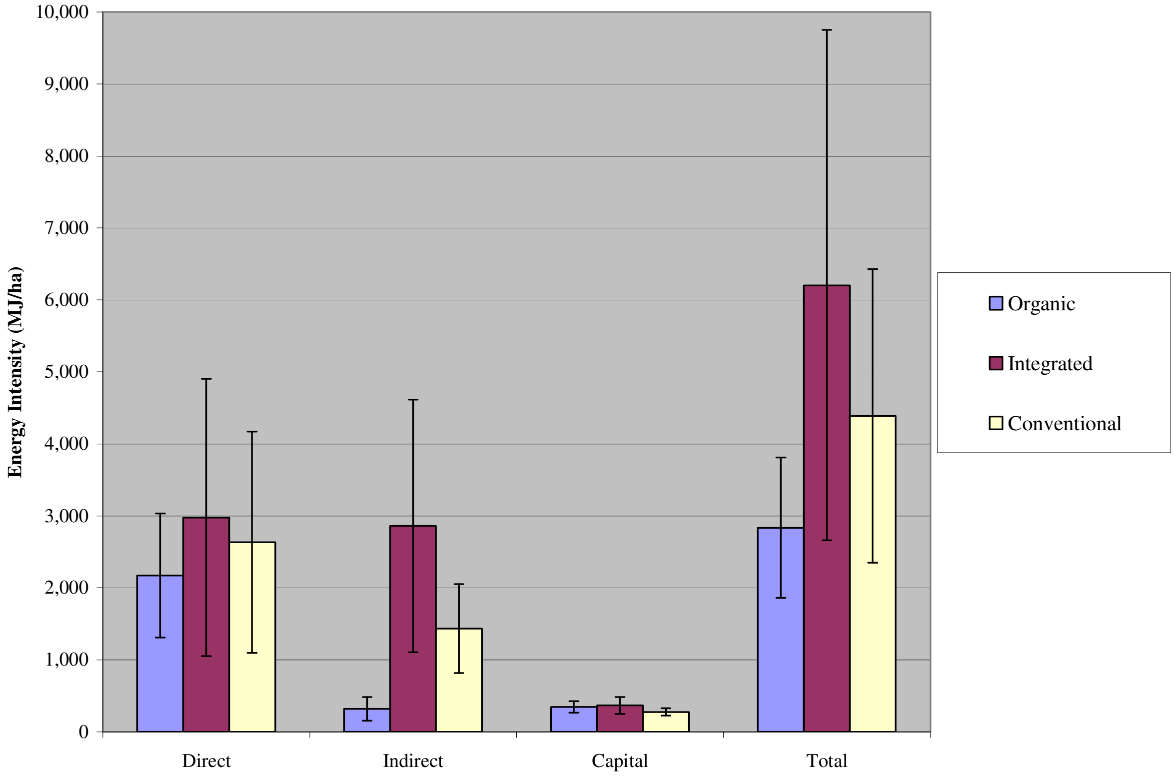
Indicator	Average, 95% confidence interval and (median)		
	Organic	**Integrated**	**Conventional**
Total energy MJ/ha	2,840 ± 980 (2,410)	6,210 ± 3,550 (4,390)	4,390 ± 2,040 (3,540)
Total energy MJ/s.u.	420 ± 190 (290)	530 ± 270 (370)	450 ± 270 (270)
MJ/$	4.0 ± 1.4 (3.3)	6.0 ± 1.5 (5.3)	5.1 ± 1.6 (4.7)
Direct %	75	46	58
Indirect %	11	45	33
Capital %	14	9	9
Renewable %	9	8	10

Removing one cluster of high input and high output farms lowers the energy intensity and reduces the variability (Table 21), although it makes the energy productivity figures slightly worse (not shown).

Table 21 Energy Intensity excluding a high input/output cluster

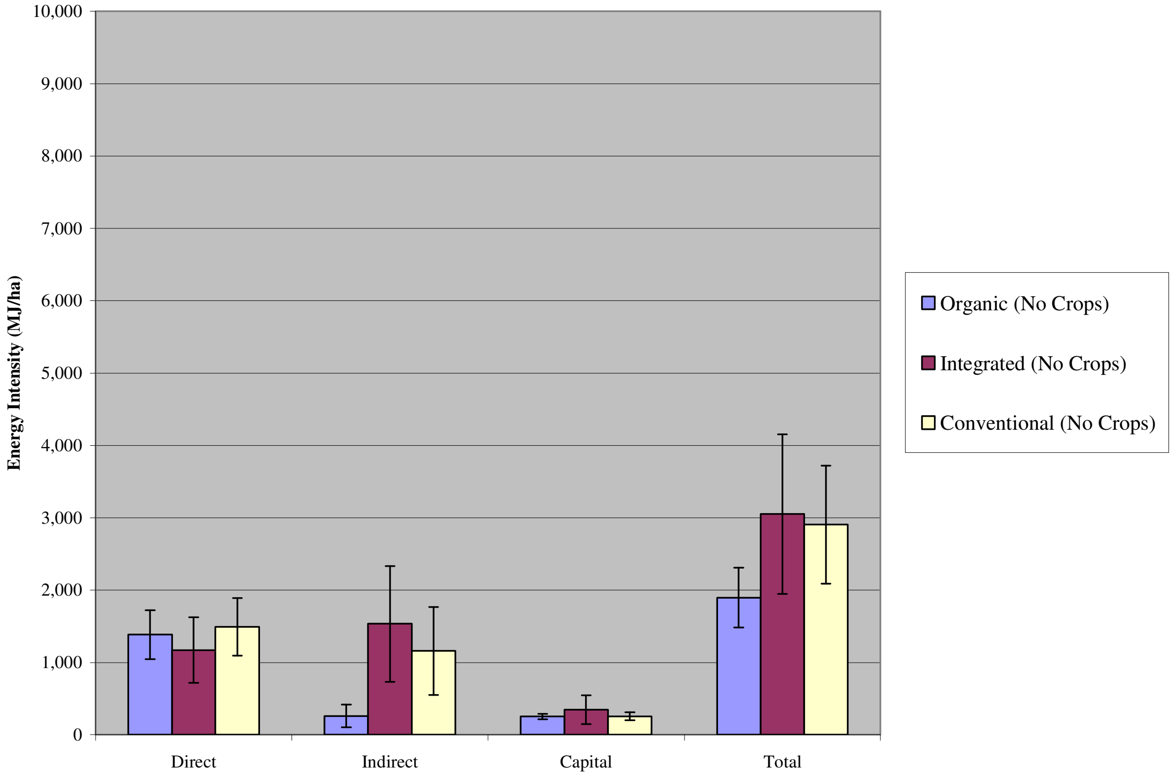
Indicator	Average, 95% confidence interval and (median)		
	Organic	**Integrated**	**Conventional**
Total energy MJ/ha	2,650 ± 990 (2,300)	4,590 ± 1,780 (3,970)	3,740 ± 1,780 (3,540)
Total energy MJ/s.u.	370 ± 170 (240)	410 ± 140 (360)	340 ± 200 (260)
MJ/$	4.1 ± 1.5 (3.6)	5.8 ± 1.6 (4.8)	5.2 ± 1.7 (5.0)

Figure 2 Energy Intensity per Hectare – All Farms



When the five organic, five integrated and two conventional farms that include cropping in their mix are removed the energy intensity and variation drops considerably as shown in Figure 3. A large part of the integrated farms diesel and nitrogen inputs are attributable to the crops as the direct energy use drops by 61%, indirect energy use drops by 46%, and total energy drops by 51%.

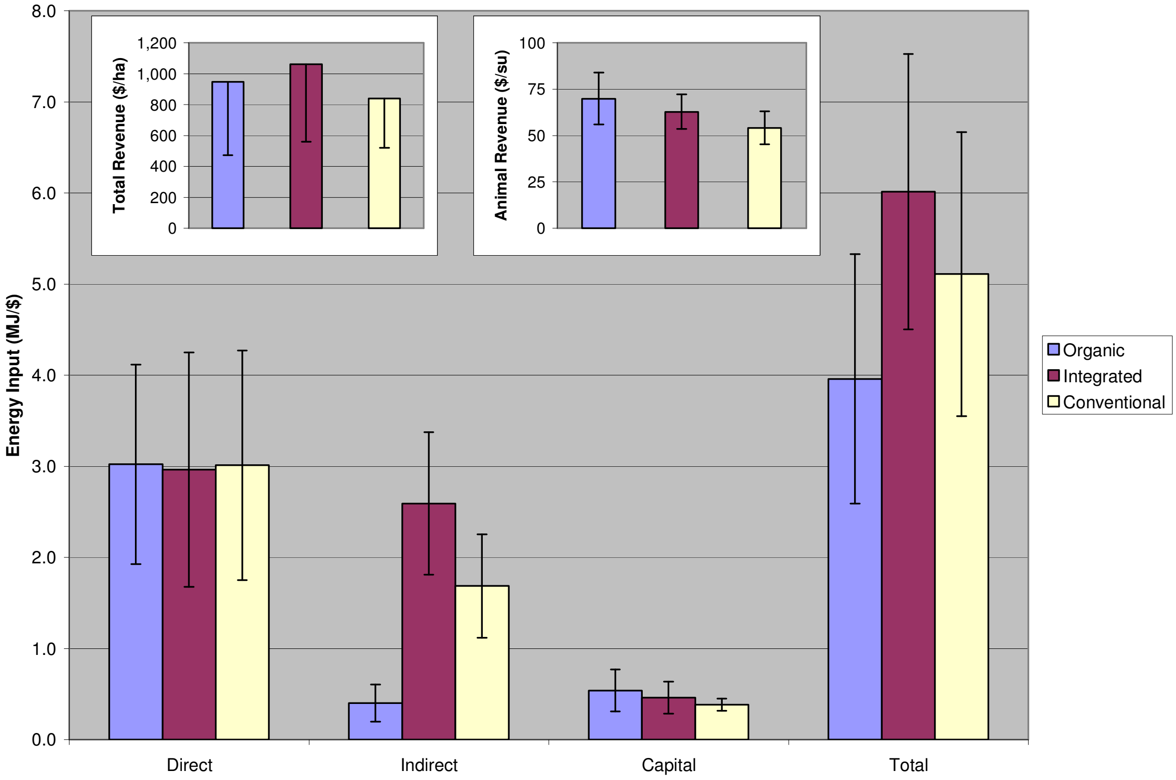
Figure 3 Energy Intensity per Hectare – Excluding Cropping Farms



Energy intensity per dollar of revenue shows a similar pattern as per hectare and per stock unit. Revenue generated from animal production is slightly higher per stock unit on the organic farms compared to the integrated and conventional farms.

While all energy figures in this report are presented in terms of primary energy, including Figure 4 below, it is interesting to consider the intensities in terms of consumer energy as a point of comparison with both the New Zealand economy and the agricultural industry as a whole (directly comparable primary energy figures are not available). In the year to March 2005 the energy intensity of the New Zealand economy was 3.6 MJ/$. This is based on total consumer energy of 534 PJ (MED, 2005) and gross domestic product (GDP) of $148,912 million (Stats, 2006). Agriculture is less energy intensive at approximately 2.7 MJ/$. The ARGOS sheep and beef farms were all very similar and slightly lower than the average New Zealand agricultural figure at 2.5, 2.6, and 2.6 MJ/$ for the organic, integrated and conventional farms respectively.

Figure 4 Primary Energy Intensity per Dollar of Revenue



3.4.2 Energy Productivity

The energy productivity indicators that have been established are per tonne of wool and per tonne of sheep carcass weight.

Wool production, based on a share of the farm revenue is allocated almost the same proportion of energy inputs across all the farm management systems being between 11 and 12%. Table 21 and Figure 5 show that while organic farms have the best (lowest) energy productivity it is not significantly different from the other two farming systems except for the indirect energy inputs. Organics median value however is almost half the median integrated and conventional farms.

Figure 6 shows that the significantly lower sheep productivity on the organic farms results in them having very similar energy productivity as the integrated farms and 34% higher than the conventional farms.

Table 21 Energy Productivity

Indicator	**Average, 95% confidence interval and (median)**		
	Organic	**Integrated**	**Conventional**
Total energy MJ/t wool	11,170 ± 3,860 (7,870)	15,680 ± 3,680 (14,240)	15,780 ± 5,830 (14,220)
Total energy MJ/t sheep carcass weight	16,000 ± 5,010 (14,180)	15,600 ± 4,270 (14,740)	11,300 ± 4,410 (10,450)

Figure 5 Energy Productivity per Tonne Wool

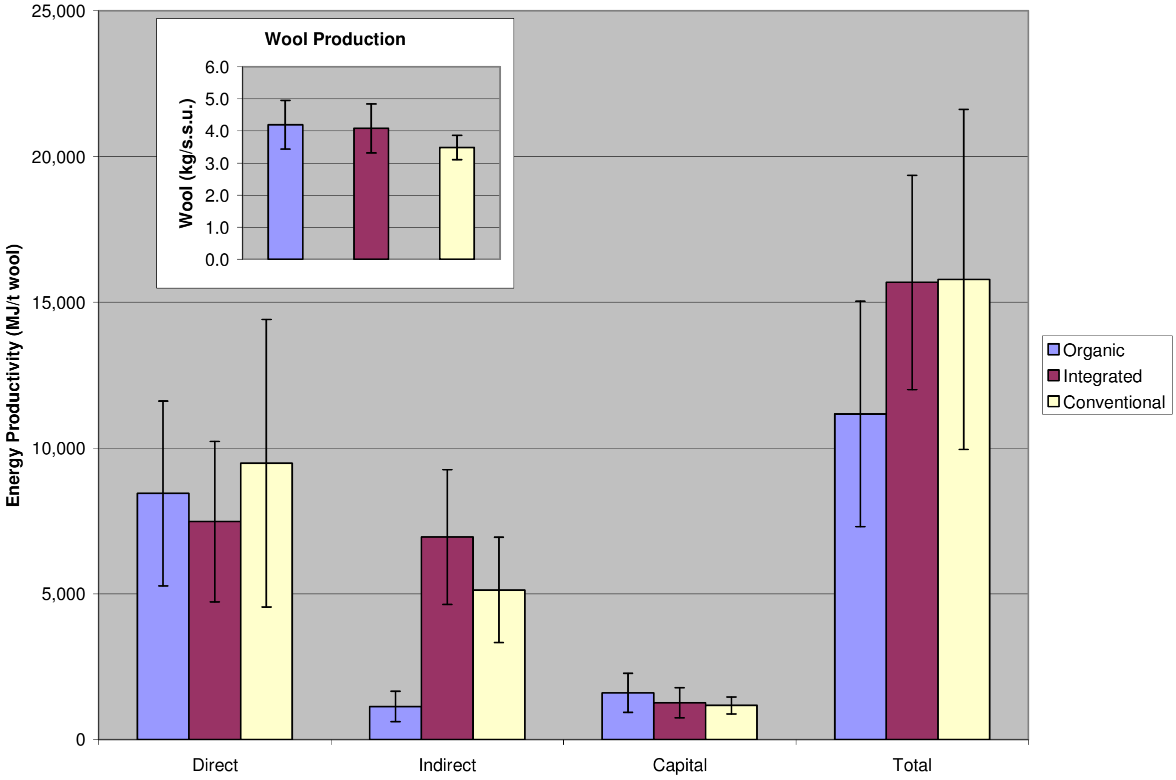
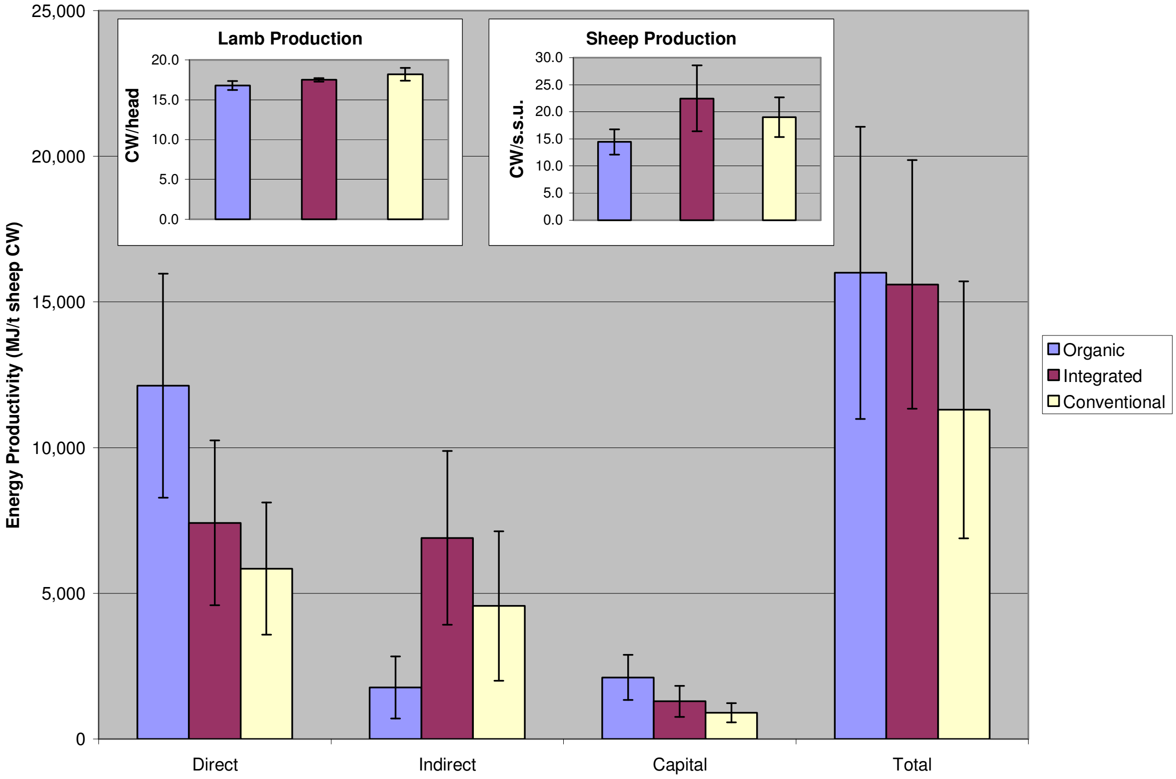


Figure 6 Energy Productivity per Tonne Sheep Carcass Weight



4. Discussion and Conclusions

Total energy indicators are an important eco-efficiency tool used as a quantitative gauge of potential environmental impacts. They are being used for policy development as well as establishing indicators that can be used in international negotiations around sustainability and market access, most noticeably as part of the “Food Miles” debate.

This study found that the total energy intensity; per hectare, per stock unit, and per dollar of revenue; across the three farming systems was not significantly different at the 5% level. The average organic farm had the lowest energy intensity, followed by conventional farms, with the integrated farms consistently having the highest energy intensity. Organic farms had an energy intensity of 2,840 MJ/ha, integrated farms were more than double (119% higher) at 6,210 MJ/ha, while conventional farms were 55% higher than organic farms at 4,390 MJ/ha. The stocking intensity was lowest on the organic farms, 8.5 s.u./ha, compared to an average of 11.4 s.u./ha on the integrated and conventional farms. This lower stocking rate made the differences in energy intensity per stock unit much smaller. Organic farms had an energy intensity of 420 MJ/s.u., while the integrated and conventional farms were 530 MJ/s.u. (22% higher) and 450 MJ/s.u. (5% higher) respectively. Removing a cluster that had high inputs and outputs reduced the energy intensity per stock unit by 12% on the organic farms and 23% on the integrated and conventional farms. On a per dollar of revenue basis the organic farms were once again the lowest at 4.0 MJ/$ with the integrated and conventional farms at 6.0 MJ/$ (50% higher) and 5.1 MJ/$ (28% higher) respectively.

Energy intensity is greatly influenced by the farms that include cropping in their production mix. Removing those farms that crop reduces the energy intensity on the organic and conventional farms by 33%, to 1,900 MJ/ha and 2,910 MJ/ha respectively, while the energy intensity on the integrated farms is more than halved from 6,210 MJ/ha to 3,050 MJ/ha. On a per stock unit basis the average organic farm more than halves its energy intensity from 420 to 200 MJ/s.u., the integrated farms drop from 530 to 300 MJ/s.u., while conventional farms go from 450 MJ/s.u. to 250 MJ/s.u..

In order to determine the energy productivity for a particular product, in a multi-product system, it is necessary to choose a methodology for allocating resources to each product stream. In the absence of any better methodology an economic approach has been used based on Farm Revenue. Wool energy productivity showed a similar pattern to the energy intensity results with the organic, integrated and conventional farms having 11,170, 15,680 and 15,780 MJ/t greasy wool respectively. Conventional farms had the lowest wool production per sheep stock unit which helped make its energy intensity similar to the integrated farms. The price received per tonne of wool was similar across the three farming systems at $2,990/t.

The energy productivity per tonne of sheep carcass weight was the only indicator which showed organic farms had the highest energy use (by 3%). This was caused by their much lower sales compared to the integrated and conventional farms, helped by higher lambing percentages and consequently a high number of sales per sheep stock unit (s.s.u.). The energy productivity was found to be 16,000, 15,600 and 11,300 MJ/tonne sheep carcass weight.

The only indicator that was consistently statistically significantly different between the farming systems was indirect energy use, which is dominated by the influence of inorganic nitrogen fertiliser applications of which organic farms do not apply any.

This project has established a set of benchmark total energy indicators. Confidence in the results will be strengthened by additional sampling in subsequent years, which now that the database has been established can be easily added to. Subsequent sampling will also allow resource use to be tracked in different seasons and stages of farm development. Further study and linkages with other disciplines is needed to answer the question as to whether these indicators are sustainable. It would be extremely interesting to progress the work and link the energy indicators with soil monitoring. Is the low energy footprint of the organic indirect energy inputs, predominantly caused by no inorganic nitrogen, utilising reserves established by previous management practices or is it sustainable in its own right?

Based on these benchmarks the next step should be to conduct sensitivity analysis and identify environmental hotspots with the objective of determining where management should concentrate when investigating ways to improve their overall environmental performance.

Due to the detailed inventory of resource use and energy flows that have been developed in this study expanding the number of impact categories and the system boundary will enable a life cycle assessment (LCA) study to be conducted. More importantly ARGOS, with its multi disciplinary approach, has the potential to address one of the problems with LCA; the ability of linking the indicators, which show potential environmental impacts, with actual impacts. Three impacts to target would be eutrophication (nutrient enrichment of ecosystems) both because of the ability to measure loss (nitrogen leaching), the impact (enhanced biomass production in waterways) and the stark contrasting differences in fertiliser use between the management systems. The other impact categories to target would be greenhouse gas emissions, part of which are linked to nitrogen fertiliser use and production intensity, and eco-toxicity, which is linked to pesticide use.

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