Seven Case Study Farms: Total Energy & Carbon Indicators for New Zealand Arable & Outdoor Vegetable Production

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CONTENTS

LIST OF ABBREVIATIONS

Energy & Power

J	joule	basic unit of energy
kJ	kilojoule	1,000 joules
MJ	megajoule	1,000,000 joules
GJ	gigajoule	1,000,000,000 joules
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	
CO_2	carbon dioxide	
EECA	Energy Efficiency and Conservation Authority	
MAF	Ministry of Agriculture and Forestry	
Vegfed	New Zealand Vegetable and Potato Grower's Federation Inc.	
IPCC	International Panel on Climate Change	
MED	Ministry of Economic Development	
FAR	Foundation for Arable Research	

Conversions

1 ha = 2.47 acres

1 l petrol = 0.92 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

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1.0 EXECUTIVE SUMMARY

The projects aim was to reduce New Zealand's energy costs in arable and outdoor vegetable production by increasing awareness, benchmarking energy use and targeting practical solutions for optimising direct energy use.

While direct energy use is often less than 5% of expenditure, cost savings from a 15% improvement in diesel and electricity use can boost profits by $4,200 on a 150 ha irrigated arable farm and by $3,000 on a 100 ha vegetable operation. Beside direct cost savings other benefits include lower labour costs, reduced repairs and less capital depreciation.

Apart for the financial benefits there is growing consumer demand for environmentally sustainable production systems which includes optimising energy use. Monitoring and tracking total energy use (direct and indirect inputs) can also provide an indicator of overall sustainability.

Total energy use not only includes the direct energy content of fuels but also the energy in extraction, manufacture and delivery of that fuel, along with the embodied energy in fertiliser, agrichemicals and capital items.

A range of energy optimisation measures have been documented from reduced tillage and tractor driver education to irrigation efficiency and split fertiliser applications.

The two case study irrigated arable operations had an average total energy input of 34,200 MJ/ha (Table 22). Of this 61% was direct energy in the form of diesel at 4,800 MJ/ha and electricity at 15,900 MJ/ha. Field operations, primarily tractor use for soil cultivation, spraying and harvesting, used 85 l/ha with a further 23 l/ha used by utes and cars for business purposes. Electricity use for irrigation was 2,000 kWh/ha. Fertiliser use accounted for 28% of total energy, which was dominated by nitrogen at 8,400 MJ/ha or 129 kgN/ha. The three arable farms investigated had the same overall energy ratio (output: input) for wheat of 3.0. This was despite one farm being a dry land operation which had significantly lower direct energy inputs which were mainly offset against lower yields and slightly higher fertiliser use.

Onion production required 50,100 MJ/ha (Table 24), 40% of which was diesel use at 319 l/ha for field operations plus 118 l/ha for transporting the crop back to a central store. Electricity was only a minor input at 1%. Fertiliser was 26% of total energy inputs at 12,900 MJ/ha and like the arable operations it was dominated by nitrogen at 8,800 MJ/ha or 135 kgN/ha. Agrichemical use was similar to fertiliser inputs at 12,000 MJ/ha and was dominated by fungicides, due to an extremely wet humid season. Approximately four times as much fungicide was applied than normal. A more normal year would have reduced the total energy use by 12% to 44,370 MJ/ha. The overall energy ratio was 2.1.

Renewable energy is mainly in the form of hydro-generation of electricity. For the irrigated arable operations 29% of energy inputs were from renewable sources. Potato production used 3% renewable energy and onions 1%, both reflecting the decreasing use of electricity.

Total carbon dioxide emissions for arable operations averaged 1.6 t/ha, while onions average 3.5 t/ha. Carbon dioxide emissions from direct energy inputs that may be subject to a future carbon tax were 1.2 t/ha for irrigated arable operations, 0.2 t/ha for dry land arable, 1.9 t/ha for potato and 1.3 t/ha for onions. At a tax rate of \$25/t CO_2 this will cost the growers \$30/ha, \$6/ha, \$47/ha and \$34/ha respectively.

Energy use has been found to be higher than previously reported in NZ studies, although there is no detailed analysis that shows the raw data to help explain the differences.

American wheat production has lower energy input per hectare, but on a yield basis this study found lower total energy use with an overall energy ratio of 3.0 compared with 2.5 in America (Table 3 and 23). Fuel use (diesel equivalents) was similar at around 81 l/ha in America and between 71 and 85 l/ha in NZ.

Energy inputs into potato production were found to be similar in this study with American findings at around 60,000 MJ/ha (Table 4 and 25). Like with arable production the overall energy ratio was better in this study at 2.7 compared to 2.2 in America. Fuel use for field operations was 294 l/ha, plus transport between the paddocks and a central store added a further 103 l/ha (total of 397 l/ha). This compares to an American study at 402 l/ha (diesel equivalents).

The results from this study can be used to benchmark an operations performance against the following set of sustainable production indicators.

Irrigated arable

	Quantity/ha	MJ/ha	%
Field operations (l)	*85*	*3,700*	*10.8*
Total diesel use (field op. + transport) (l)	110	4,800	14.0
Total electricity use (kWh)	1,958	15,900	46.6
Total fertiliser	-	9,500	27.7
Total agrichemicals	-	1,200	3.6
Total capital	-	2,800	8.1
Total energy	**-**	**34,200**	**100**
Yield wheat (tonnes)	7.2	103,000	
Overall Energy Ratio for wheat = 2.9			
Renewable energy (kWh)	1,229	10,000	29
Carbon emissions (t CO_2)	1.5		
Taxable carbon emissions (t CO_2) & (\$)	1.2, \$30		

Dry land arable

	Quantity/ha	MJ/ha	%
Field operations (l)	*71*	*3,100*	*15.5*
Total diesel use (field op. + transport) (l)	87	3,800	18.7
Total electricity use (kWh)	0	0	0.0
Total fertiliser	-	12,200	60.6
Total agrichemicals	-	1,100	5.6
Total capital	-	3,000	15.0
Total energy	**-**	**20,200**	**100**
Yield wheat (tonnes)	4.3	61,500	
Overall Energy Ratio for wheat = 3.0			
Renewable energy (kWh)	0	0	0
Carbon emissions (t CO_2)	1.8		
Taxable carbon emissions (t CO_2) & ($)	0.2, $6		

Onion production

	Quantity/ha	MJ/ha	%
Field operations (l)	*319*	*13,900*	*27.7*
Total diesel use (field op. + transport) (l)	460	20,000	39.6
Total electricity use (kWh)	317	2,600	1.3
Total fertiliser	-	12,800	25.7
Total agrichemicals †	-	12,000	24.0
Total capital	-	4,700	9.4
Total energy		**50,100**	**100**
Total energy (incl. packhouse/office)	-	52,100	
Yield (tonnes)	59	104,400	
Overall Energy Ratio (output: input) = 2.1			
Renewable energy (kWh)	49	400	0.8
Renewable energy (kWh) (incl. postharvest inputs)	200	1,600	3
Carbon emissions (t CO_2)	3.5		
Taxable carbon emissions (t CO_2) & ($)	1.3, $33		

† Due to an extremely wet and humid season this figure is twice as large as normal

Potato production

	Quantity/ha	MJ/ha	%
Field operations (l)	*294*	*12,800*	*21.3*
Total diesel use (field op. + transport) (l)	422	18,400	30.7
Total electricity use (kWh)	360	2,900	4.9
Total fertiliser	-	25,000	41.7
Total agrichemicals †	-	8,300	13.8
Total capital	-	5,400	8.9
Total energy		**60,000**	**100**
Total energy (incl. packhouse/office)	-	70,700	
Yield (tonnes)	50	161,500	
Overall Energy Ratio (output: input) = 2.7			
Renewable energy (kWh)	227	1,800	3
Renewable energy (kWh) (incl. postharvest inputs)	1,057	8,600	12
Carbon emissions (t CO_2)	3.9		
Taxable carbon emissions (t CO_2) & ($)	1.9, $47		

† Due to an extremely wet and humid season this figure is 2.5 times larger than normal

2.0 INTRODUCTION

2.1 Project Description

2.1.1 Aims and Objectives

The aim of this project was to reduce energy costs in New Zealand's arable and commercial outdoor vegetable industries.

The project was established with four objectives:

1. Identify and document practical solutions to optimise direct energy use (predominantly diesel and electricity).
2. Develop an energy management plan template (spreadsheet) for use by arable and outdoor commercial vegetable growers.
3. Benchmark the actual on-farm energy use of six operations, three arable and three outdoor vegetable operations.
4. Develop baseline energy use indicators in order to gauge the effectiveness of any energy efficiency gains. Prepare and deliver an education programme on energy minimisation techniques (primarily aimed at driver education and resource tracking techniques).

A number of national and international studies have established a set of energy indicators for different crop types (Smith and McChesney, 1979; Nguyen and Haynes, 1995; Pimentel et al., 1983). In response to increasing demands from produce retailers to monitor and track energy inputs and to be able to asses this against world best practice, objective two was to establish a template for tracking actual on-farm energy use.

As the project has progressed it has also incorporated the development of a set of carbon indicators. Energy and carbon indicators are very closely linked and as a consequence of New Zealand ratifying the Kyoto Protocol, policy makers and industry need to monitor and track carbon dioxide (CO_2) emissions.

2.1.2 Benefits of Energy Monitoring

Direct energy use is usually less than five percent of an arable and outdoor vegetable operation's expenditure and is subsequently given equally low consideration. The exception is spray irrigated properties in dry regions like Canterbury where high electricity use can lift direct energy costs to approximately twenty percent of expenditure.

Despite the low overall cost of direct energy use savings that are identified and implemented improve profitability. In an industry where margins are low even small savings with quick payback periods can be significant. The other component of implementing energy saving strategies is the multiplier effect, which includes savings in labour, machinery repairs and maintenance, and capital depreciation.

Apart from improved profitability there are strong environmental benefits to be derived from greater energy efficiency. These are both direct in terms of reduced carbon dioxide emissions from burning fossil fuels and indirectly through improved soil structure from fewer tillage operations.

Monitoring and tracking both direct and indirect energy provides a simple means of measuring an operations overall environmental performance. For example improvements in fertiliser and chemical applications will be reflected in an overall improvement in total energy use.

2.1.3 Funding

This project has been jointly funded through a grant from the Ministry of Agriculture and Forestry (MAF) Sustainable Farming Fund and two industry organisations, Foundation for Arable Research (FAR) and The NZ Vegetable and Potato Growers Federation (Vegfed). Growers have contributed time and resources through their involvement in the case study farms.

2.2 Methodology

2.2.1 Consumer and Primary Energy

Consumer energy is defined as the energy delivered to the consumer, for example the kilowatt-hours recorded on the electricity meter or the actual calorific value of fuel available to an engine. Primary energy is the sum of consumer energy plus all the other energy inputs that go into delivering that energy to the consumer. This includes the energy used in such processes as drilling, mining, refining, generation and transport.

When calculating total energy use it is necessary to use primary energy, so that both direct and indirect energy sources are being accounted for on the same basis. When investigating initiatives to reduce direct energy use we tend to focus on consumer energy, which is a much less abstract concept and can be described in terms of litres and kilowatt hours.

2.2.2 Direct Energy Input

Direct energy is that energy used directly by the operation and is most easily recognised as energy e.g. diesel, petrol and electricity.

2.2.3 Indirect Energy Input

Indirect energy is that energy which is embodied in machinery, buildings, agrichemicals and fertilisers. Indirect energy is calculated using previously determined coefficients. For example, the production of nitrogen fertiliser requires large quantities of energy for its synthesis from natural gas which must be included in a farms overall energy use in order to determine the true total energy input.

2.2.4 Total Energy Use

It is important to know the total energy use, the sum of the direct and indirect energy, to get a true picture of the energy flows in and out of the farm. This data is then available for comparing farm performance both between similar farms or between growing systems e.g. conventional versus organic and internationally between countries.

2.2.5 Energy Analysis

In agricultural systems there are four critical parameters which describe energy use (Smith & McChesney, 1979).

Overall Energy Ratio:	The amount of energy returned, divided by the amount of energy that must be expended to obtain that return.
Energy Intensity:	The amount of auxiliary energy expended per hectare.
Energy Productivity:	The amount of auxiliary energy expended per tonne of product. Smith & McChesney (1979) used the inverse of this, the number of kilograms of product per megajoule of auxiliary energy expended.
Net Energy Yield:	The energy output of harvestable product per hectare minus the auxiliary input per hectare.

2.3 New Zealand Energy Studies

2.3.1 History

The study of energy use in New Zealand agriculture began in the late seventies and continued through until the early eighties. There was then a period during the late eighties and most of the nineties where very little work was done.

The increasing interest in organic production systems saw a study in 1995 (Nguyen and Haynes) comparing conventional with alternative mixed cropping farms in Canterbury. In the late nineties and continuing on today the study of on-farm energy use has been picked up again.

It is not surprising that the study of energy closely matches changes in its price. In the late seventies there was the oil shocks and the building of the so-called “think big” energy projects. In the late nineties and the beginning of the new century oil prices started to increase again, although not nearly to the same extent as they did in 1979. However, this time coupled with rising energy cost there is a new threat from overseas trading partners using environmental compliance as a form of non-tariff barrier. Energy use is one of the environmental indicators commonly used.

2.3.2 Energy Distribution

In order to answer the question of how to optimise energy input it is essential to determine where energy is being used in order to target any improvement measures where the greatest benefit will occur.

In 1975 the Joint Centre for Environmental Sciences based at the University of Canterbury estimated the breakdown of energy use from a Department of Statistics survey. The results are shown in Table 1.

Table 1 Energy Inputs to Outdoor Vegetables in New Zealand

Operation	**Percentage**
Fuel and power	39
Fertiliser and seeds	25
Machinery	10
Sprays	5
Packaging	7
Buildings and other	14
Total	**100**

2.3.3 Energy Intensity

Research conducted in NZ between 1979 and 1995 showed the following energy intensities.

Table 2 NZ Study of Energy Intensity for Various Crops

Crop	**Energy Intensity (MJ/ha)**
Oats	6,000 [a]
Maize	15,000 [a] and 36,000 [b]
Outdoor vegetables	18,000 [a]
Wheat	10,000 [c]
Barley	9,000 [c]

[a] Smith and McChesney (1979)
[b] McChesney et al. (1982)
[c] Nguyen and Haynes (1995)

The study by McChesney et al. in 1982 on maize would suggest that the earlier energy intensity figures for oats and outdoor vegetables may need revising upwards.

When McChesney et al. (1982) compared the energy input between NZ and the UK, they found that for cereals the energy requirement in NZ was half that of the UK. However, the opposite was true for potatoes where total energy requirements were almost 60% higher in NZ. NZ's favourable climate and low use of nitrogen fertiliser explained the low cereal energy input. Low nitrogen input was due to the use of clover fixed soil nitrogen in the cereal rotation mix. There was not an explanation why NZ potato production used more energy than in the UK.

2.4 Overseas Energy Studies

2.4.1 Energy Intensity and Distribution

Pimentel et al. (2002) found the following distribution of energy use for both potato and winter wheat production in America. The American work is in calories and has been converted to joules (1 calorie = 4.184 joules).

The first column of energy intensity figures are as they appeared in the Pimentel et al. (2002) study followed by a second set of revised figures that have been calculated using the quantity of each input multiplied by the same energy coefficient that was used in this study. The differences are not significant but it makes for comparisons between this study and Pimentel et al.'s on a more even basis.

Table 3 Energy Inputs for Winter Wheat Production in the United States

Item	Quantity/ha	Energy Intensity		Percentage
		MJ/ha	Revised [a] MJ/ha	
Petrol (litre)	26.2	1,473	1,389	9.2
Diesel (litre)	46.3	2,364	2,153	14.2
Total Fuel	**-**	**3,837**	**3,542**	**23.4**
Electricity (kWhr)	13.3	172	116	0.8
Nitrogen (kg)	67.3	5,322	4,446	29.4
Phosphorus (kg)	25.8	586	506	3.3
Potassium (kg)	7.0	29	21	0.1
Total Fertiliser	**-**	**5,937**	**4,973**	**32.8**
Seed (kg)	104.3	912	912	6.0
Insecticides (kg)	0.3	21	16	0.1
Herbicides (kg)	1.7	1,674	1,720	11.4
Total Agrichemicals	**-**	**1,695**	**1,736**	**11.5**
Transportation (kg)	182.6	515	515	3.4
Machinery (kg)	19	3,347	3,347	22.1
Total		**16,414**	**15,140**	

[a] The column of revised energy intensities is calculated using the same energy coefficients as were used in this study.

The total wheat yield is 2.67 t/ha and the overall energy ratio (OER) is 2.5.

Table 4 Energy Inputs for Potato Production in the United States

Item	Quantity/ha	Energy Intensity		Percentage
		MJ/ha	Revised [a] MJ/ha	
Petrol (litre)	272	11,506	10,853	18.7
Diesel (litre)	152	7,259	6,612	11.4
Total Fuel	**-**	**18,765**	**17,465**	**30.1**
Electricity (kWh)	47	565	381	0.7
Nitrogen (kg)	231	17,966	15,015	25.9
Phosphorus (kg)	220	3,812	3,300	5.7
Potassium (kg)	111	1,515	1,110	1.9
Total Fertiliser	**-**	**23,292**	**19,425**	**33.5**
Seed (kg)	2,408	6,184	6,184	10.7
Insecticides (kg)	1.8	753	558	1.0
Herbicides (kg)	3.1	1,297	1,333	2.3
Fungicides (kg)	3.0	1,255	630	1.1
Total Agrichemicals	**-**	**3,305**	**2,521**	**4.3**
Transportation (kg)	2,779	9,652	9,652	16.6
Machinery (kg)	31	2,402	2,402	4.1
Total		**64,166**	**58,030**	

[a] The column of revised energy intensities is calculated using the same energy coefficients as were used in this study.

The total potato yield is 38.8 t/ha and the overall energy ratio is 2.16.

In an earlier study in 1980 Pimentel et al. found American potato production ranged between 42,221 to 82,274 MJ/ha or an OER of between 0.4 and 4.6.

Studies in the UK by White (1975) showed the following energy intensities.

Table 5 UK Study of Energy Intensity for Various Crops

Commodity	Energy Intensity (MJ/ha)
Barley	18,100
Wheat	19,600
Carrots	25,100
Potatoes	52,000

2.5 Energy Management

2.5.1 Opportunities for Optimising Energy Input

Measurers for reducing energy use exist throughout the production system. Some examples include:

Land Preparation:

- Reduced tillage
- Driver education and awareness
- Improved matching of tractors and implements to tasks

15% fuel savings [a]

  - Arable $7.25 / ha
  - Vegetable $28.75 / ha

Irrigation:

- Efficient pumping
- Efficient water application
- Better soil moisture monitoring and irrigation scheduling

15% electricity savings [a]

  - Arable $21.00 / ha
  - Vegetable $1.25 / ha

Applying Nutrients:

- Reducing applications
- Split applications matched to plant demand
- Regular soil and plant analysis
- Biological nitrogen fixation

Pest and Disease Control:

- Greater use of integrated pest management
- Resistant varieties of seeds/plants
- Ultra low volume sprayers

Transport:

- Larger central operations
- Driver education

Post Harvest and Administration:

- Replace incandescent bulbs to compact fluorescent
- Switch monitors off over night and enable power down features
- Investigate fast opening / closing doors
- Better matching motors to operations
- Time and motion sensors

[a] Average of surveyed operations

Improved sustainable practices of soil and water conservation, and reduced fertiliser and chemical applications will have both an environmental and financial benefit that can be represented by improved total energy indicators.

2.5.2 Alternative Energy Sources

This project has not investigated the opportunities of using alternative energy sources, however any measures which increase the use of renewable energy is positive. New Zealand production systems traditionally have had a high component of renewable energy compared to our overseas competitors due largely to the hydrogenation of electricity. This has reduced in recent years as gas and coal generation of electricity increases. In situations where New Zealand does not have a comparative advantage in lower energy inputs, demonstrating that a large portion of that energy has come from renewable sources will be extremely important.

2.5.3 Energy Conservation Methods for Current Grower Practices

Ralf Sims of Massey University published a report entitled On-Farm Energy Supply and Conservation in 1983. Much of the information which follows was taken from this publication. At the same time a tractor driver education programme was developed called Tractor Facts. Information from this programme was incorporated in two tractor driver education workshops that were conducted as part of this project.

2.5.3.1 Tractor Selection

Traction

a) Tyre size. The use of larger than standard tractor tyres can decrease fuel consumption by up to 10%. The greatest benefit is in soft moist conditions due largely to the increase in “footprint area” and the ability to carry equal loads at lower inflation pressures. Tractors may be sold with small tyres to reduce the initial cost, but the fitting of both larger diameter and wider tyres is a small extra when consideration is made of the increased efficiency.
b) Dual tyres. Same benefit as fitting larger tyres
c) Radial tyres. The market in NZ is about 50/50 for radial and crossply tractor tyres. Radial tyres can decrease fuel consumption by up to 10% when operating at low inflation pressures on harder soils, due to the increased contact area. At inflation pressures over 140 kPa there is little difference in terms of energy efficiency between the two tyre types.
d) Tread pattern. There seems to be no effect on fuel consumption between normal agricultural tread patterns.
e) Crawler tractors. For cultivation, this can decrease fuel use by 20% compared with two wheel drive tractors due to the increased footprint and lower rolling resistance.
f) Four wheel drive tractors. Tests have shown that there is up to a 10% fuel saving for unequal sized four wheel drives and 15% for equal sized wheels compared to two wheel drive tractors under soft soil conditions. On hard surfaces there is very little difference. Where attention is paid to tyre size and correct ballasting, two-wheel drive could expect to reduce fuel consumption by up to 20% in many situations.

Tractor Size

Providing tractors are correctly ballasted, tyred and loaded, specific fuel consumption will be relatively constant and independent of tractor size. Thus in heavy load applications such as primary and secondary cultivation, tractor size will have little influence on fuel consumption per hectare.

Inefficiencies often occur where tractors are not loaded to operate within their most fuel efficient range. Correct loading is more difficult to achieve for large tractors when on light load applications such as mowing, rolling and drilling etc. For example, a 50 kW tractor used to power an 8 metre boom sprayer and pump would consume approximately 1.5 litres of fuel/ha, whereas a 30 kW tractor on the same job, would require just 1.0 litre/ha.

Where it is not possible to eliminate the light load applications for a tractor by either multi-coupling or using larger field equipment, several other alternatives are possible.

a) Use of a contractor
b) A tractor on light load applications, often solely for transport purposes, could be replaced by a utility or motor cycle wherever possible.
c) Purchase different size tractors

2.5.3.2 Implement Selection

Matching of Tractor and Implement
For optimum fuel efficiency implements must be selected and used to maintain correct tractor loading.

Hydraulic 3-Point Linkage Equipment
The use of 3-point or 2-point linkage mounted equipment, in preference to trailed equipment, will often both increase field efficiency and reduce the tractor ballast required.

Power-Take-Off Equipment
Equipment powered directly through the p.t.o. can achieve up to a 50% fuel saving over draught particularly for cultivation. This saving is possible due to the reduction of wheel slip and lower rolling resistance.

2.5.3.3 Tractor and Implement Operation

Fuel Consumption Records
Very few growers keep accurate tractor fuel consumption records on either a per hour or a per hectare basis. Farmers should be encouraged to keep fuel consumption records. The simplest means of recording fuel is with a meter at the bowser; alternatively a dipstick calibrated to suit the machine’s fuel tank could be used.

Engine Speed and Gear Selection
For maximum efficiency tractor power should closely match implement demand to ensure the engine is working at or near maximum power. However some operations will require only part engine power. Under these conditions significant fuel savings are possible by selection of a higher gear and lower engine speed. Correct engine speed and gear selection has become the centrepiece of many overseas tractor efficiency campaigns and catch phrases such as “change up – throttle back” are commonly used. Use of this technique could achieve fuel savings of up to 20%. In a trial as part of this project a grower achieved fuel savings of 10-15% during rotary cultivation by changing the gear selection on the cultivator and throttling back.

It is considered that there is room for improvement in tractor driver’s habits.

Traction Efficiency

Traction efficiency involves a balance between wheel slip and rolling resistance. Too much wheel slip is a result of the tractor being too light, and will use excessive fuel. On the other hand minimal wheel slip indicates excessive ballast. An understanding of the principles of wheel slip and ballast would lead to significant fuel savings. The optimum wheel slip for four wheel drive tractors in cultivated soil is between 8-12%, in uncultivated soil it lowers to 6-10%.

Hydraulics

The use of draught control or pressure control to transfer weight from the implement to the tractor is the most efficient means of adding weight to a tractor. Fuel savings in the order of 30% have been recorded when comparing draught operated implements with depth wheel controlled implements.

A survey (unpublished) on tractor operation on 12 farms in Canterbury suggested that ballasting, use of improved tractor hydraulic systems, and increased driver awareness of the hydraulic system capabilities, were the areas where the greatest increases in efficiency could be made. It was considered in many cases, savings in the order of 30% could be achieved.

Tyre Inflation Pressure

In soft conditions lower tyre pressures (e.g. 80 kPa) give increased contact area, less soil compaction, reduced rolling resistance and hence increased efficiency. On hard surfaces or for road work, inflation pressures should be increased (e.g. 150 kPa) to reduce tyre wear and rolling resistance. The use of lower pressures on soft ground can give fuel savings of up to 5%.

Power-Take-Off Operation

The efficiency of most p.t.o. driven equipment will decrease if not driven at the recommended speed (normally 540 or 1000 rpm).

Idling

Idling for more than 20 seconds is wasteful as “start-up” fuel is usually equivalent to no more than 15 seconds use at idle. If the engine is turbo charged then consideration must be given to letting the engine slowly cool when determining the minimum and maximum idling time.

Field Efficiency

If field efficiency of a tractor-implement combination can be improved, worthwhile fuel savings are possible. Field efficiency can be improved by:

(a) Farm layout
(b) Travel patterns
(c) Large paddocks
(d) Implement type, for example reversible ploughs

2.5.3.4 Tractor and Machinery Maintenance

Tractors

Regular servicing could reduce diesel consumption by 10%. Similar savings would be expected from regular servicing of petrol engines with particular attention to the ignition system. To achieve these savings a rigorous servicing schedule is required. Tractor drive tyres with excessively worn tread lugs should be replaced, especially in softer conditions.

Machinery

Regular greasing will ensure optimum efficiency. Regular sharpening and adjustment of knives and cutting elements will reduce fuel consumption.

3.0 METHODOLOGY

In order to determine the energy flows from the seven case study operations, surveys were conducted covering a 12-month period.

3.1 Farm Selection and Boundary Definition

Seven case study farms were chosen by the respective industry organisation. A brief description of each farm is given below in Table 6.

Table 6 Farm Descriptions

Farm Number	Operation	Region	Irrigated
A1	Arable	Canterbury	Yes
A2	Arable	Canterbury	No
A3	Arable	Canterbury	Yes
AV	Arable & Outdoor Vege	Canterbury	Yes
V1	Outdoor Vege	Franklin	Yes
V2	Outdoor Vege	Franklin	Yes
V3	Outdoor Vege	Franklin	Yes

For the purpose of this study the energy inputs that go into the “on-farm” production system are those consumed within the physical boundaries of the operation before the postharvest chain begins. Where an operation had different parcels of land scattered around the district it included transporting goods and product to and from that land. Postharvest inputs were excluded although electricity use for operating grading machines, coolstores and offices has been separately itemised as it is a grower cost that they need to optimise the performance of. Total energy inputs are exclusive of this postharvest electricity input unless otherwise stated. Even though some growers transport product after it was graded this was also excluded given that it is part of the postharvest chain.

The energy requirement to manufacture consumables like fertiliser and agrichemicals is included as indirect energy. Capital items such as buildings and machinery also require energy to manufacture, which is added into the indirect energy component divided over the working life of the item.

3.2 Direct Energy Inputs

3.2.1 Petrol, Diesel and Lubricants

The gross energy content or consumer energy of diesel, petrol and lubricants is 35.4, 32.4 and 38.7 MJ/l respectively (MED, 2002). The primary energy content, which includes an allowance for the fuels production and delivery, adds an extra 23% (Wells, 2001). This makes the total energy content for diesel, petrol and lubricants 43.5, 39.9 and 47.6 MJ/l respectively. These figures are summarised in Table 12.

The reference to liquid fuels in this report refers to the aggregated figure of diesel, petrol and lubricants. Some operations used a small quantity of petrol for road vehicles and this was converted into equivalent litres of diesel on the basis of energy content. The conversion used was 1 litre of petrol equals 0.92 litres of diesel.

3.2.2 Electricity

The consumer energy content of electricity is 3.6 MJ/kWh. Based on electricity generation in 2000 of 277 PJ and consumption of 122 PJ (MED, 2002) the primary energy content is much higher at 8.14 MJ/kWh. This takes into account electricity conversion losses in generation (140PJ) and transmission losses (12PJ), i.e. it takes 2.26 kWh of primary energy to supply 1 kWh to the consumer. This is similar to what Wells (2001) reported of 8.18 MJ/kWh based on 1997 data. These figures are summarised later in Table 12.

3.2.3 Fuel Use by Contractors

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

Fuel consumption data was developed by McChesney (1981) and Bone et al. (1996) for various farm activities, on a per hectare basis, see Table 7.

Table 7 Average Diesel Consumption Rates for Agricultural Operations

Activity	Fuel Use	Activity	Fuel Use
Ploughing	18 l/ha	Direct Drilling	10 l/ha
Cultivating	6 l/ha	Spraying	3 l/ha
Discing	12 l/ha	Fertiliser Spreading	3 l/ha
Rolling	4 l/ha	Aerial Topdressing	7 l/ha
Power Harrowing	8 l/ha	Aerial Spraying	0.035 l/ha
Light Harrowing	4 l/ha	Road Cartage	0.079 l/tonne-km
Conventional Drilling	5 l/ha		

An alternative method to calculate fuel consumption is to multiply 0.35 litres of diesel per hour for every kilowatt of power output (Martin, G. 1996). For example an 80 kW tractor (107 hp) engaged in heavy duty work at 75% of maximum power will use approximately 21 l/hr.

80 kW x 0.75 x 0.35 = 21 l/hr

3.3 Indirect Energy Inputs

3.3.1 Fertilisers

Fertiliser is the most significant indirect energy input, in particular nitrogen fertiliser because of its high use and high energy cost to manufacture.

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

Table 8 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 8 Energy Requirements to Manufacture Fertiliser Components

Component	Energy Use (MJ/kg)
N	65
P	15
K	10
S	5
Lime	0.6

3.3.2 Compost

It was estimated that it took 1 MJ/kg of dry matter to produce the raw material for compost, plus a little energy to turn the compost (Wells per. comm.). Total energy use was estimated at 1.1 MJ/kg.

3.3.3 Agrichemicals

The energy requirement to manufacture agrichemicals ranges between 100 - 440 MJ/kg of active ingredient (ai). Energy involved in formulating, packaging and transportation adds approximately a further 110 MJ/kg ai. Table 9 shows the energy input for various agrichemical categories. This has been adapted from Pimentel (1980) Handbook of Energy Utilisation in Agriculture having removed the formulations that have been withdrawn form the market.

Table 9 Energy Inputs for Various Agrichemicals

Agrichemical	Production of active ingredient (ai)	Formulation, Packaging and Transport	Total (MJ/kg of ai)
Herbicide, Preglone and Glyphosate	440	110	550
Herbicide, excluding Preglone and Glyphosate	200	110	310
Herbicide, General	320	110	430
Insecticide	185	126	310
Fungicide	97	113	210

3.4 Capital Energy

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.

3.4.1 Self Propelled Vehicles and Implements

Table 10 gives the energy coefficient for farm vehicles and implements. These figures include the embodied energy of the raw materials, construction energy, an allowance for repairs and maintenance, and international freight (Wells, 2001).

Table 10 Energy Coefficients of Vehicles and Implements

Capital Item	Energy Coefficient (MJ/kg)	Working Life (years)
Tractors	160	15
Heavy Trucks	160	15
Light trucks and utilities	160	15
Motor bikes	160	10
Farm implements	80	20

3.4.1.1 Tractors

As most operators know the power rating of their tractors rather than their weight, Wells (2001) developed an equation that related weight to power.

$$\text{Weight} = 40.8\ \text{Power} + 190 \qquad R^2 = 0.936$$

3.4.1.2 Light Trucks and Utilities

Information published by the Automobile Association shows that the weight of most modern utilities range between 1,300 to 1,500 kg. An average value of 1,400 kg was used. This is equal to 224,000 MJ or 15,000 MJ/year. Note the weight displayed in diesel vehicles for road user tax purposes includes the fully loaded weight.

3.4.1.3 Motor Bikes

A survey conducted by Wells (2001) found that the average quad bike weighed 190 kg and two wheel bikes were assumed to weigh 90 kg.

3.4.2 Buildings

The energy associated with implement and packing type sheds is 600 MJ/m^2 while the office areas were calculated at a rate of 2,000 MJ/m^2.

3.5 Energy Output

While an operation consumes energy it also captures energy contained within the crop. This principle is used to calculate the overall energy ratio (OER), $\text{energy}_{\text{output}} : \text{energy}_{\text{input}}$. This measure has been used in a number of overseas studies as well as the NZ diary industry study by Colin Wells (2001), although sometimes the ratio is around the other way.

The typical energy content of different crops is shown in Table 11.

Table 11 Energy Content of Arable and Vegetable Crops

Crop	Energy Content (kJ/kg or MJ/tonne)
Cabbage [a]	1,000
Cauliflower [a]	1,050
Lettuce [a]	230 kJ/head (6”)
Onion [a]	1,760
Potato [a]	3,230
Pumpkin [a]	1,090
Spinach [a]	590
Barley [a]	14,810
Pea [a]	3,390
Wheat [a]	14,310
Barley straw [b]	5,700 (6,800 MJ/t DM)
Wheat straw [b]	5,100 (6,000 MJ/t DM)

Source: [a] USDA and ARS, 2003
[b] Fleming, P.H., et al., 1996

3.6 Carbon Dioxide Emissions

Carbon dioxide is released when carbon is oxidised during the burning process of fuels. These emissions are primarily dependent on the carbon content of the fuel. Due to the molecular weight ratio of carbon dioxide to carbon (44:12), multiplying the weight of carbon by 3.6667 gives the quantity of carbon dioxide emitted when the carbon is oxidised.

3.6.1 Carbon Dioxide Emissions from Direct Fuel Inputs

Energy and carbon data for all commercial fuels is available from both domestic and international databases. However, because fuel qualities and emission factors may differ markedly between countries, the Intergovernmental Panel on Climate Change (IPCC) recommends that inventories should be prepared using local emission factors and energy data where possible. The consumer energy values in Table 12 were obtained from the NZ Energy Data File (MED, 2002). In the report by Wells (2001) he estimated that each unit of liquid fuel required an additional allowance of 23% to take into account the energy required for extraction, processing, refining and transport. This extra energy is shown in Table 12 as the primary energy content.

Table 12 Energy Values of Direct Fuel Inputs

Fuel	Energy Units	Energy $_{consumer}$	Energy Coefficient	Energy $_{primary}$
Diesel	MJ/l	35.4 [a]	1.23 [b]	43.5
Petrol	MJ/l	32.4 [a]	1.23 [b]	39.9
Lubricant	MJ/l	38.7 [a]	1.23 [b]	47.6
Electricity	MJ/kWh	3.6	2.26	8.1

Data sources:
[a] NZ Energy Data File 2002 (MED)
[b] Wells 2001

There is a direct relationship between energy and carbon content. Table 13 shows the carbon dioxide emissions based on both consumer and primary energy units.

Table 13 Carbon Dioxide Emissions of Direct Fuel Inputs

Fuel	Direct Emissions ($gCO_2/MJ_{consumer}$)	Figurative Emissions ($gCO_2/MJ_{consumer}$)	Total Emissions ($gCO_2/MJ_{consumer}$)	Total Emissions ($gCO_2/MJ_{primary}$)
Diesel	74.1 [a]	6.7 [b]	80.8 [a + b]	65.7
Petrol	69.3 [a]	6.7 [b]	76.0 [a + b]	61.8
Lubricant	36.7 [a]	6.7 [b]	43.4* [a + b]	35.3
Electricity (grid average)			43.1 [a + c]	18.3
Electricity (grid margin)			125.0 [d]	55.3

* assumes 50% of the lubricant is oxidised during use

Data sources:
[a] NZ Greenhouse Gas Emissions 1990-2001 (converted from g C/MJ)
[b] Wells 2001
[c] NZ Energy Data File 2002 (MED)
[d] Per comm. Ted Jamieson EECA, 2003

3.6.2 Carbon Dioxide Emissions from Indirect Inputs

Carbon dioxide is released during the mining, processing and transportation of fertiliser, agrichemicals and the components that make up capital equipment.

Like the energy coefficients the total carbon dioxide emissions for fertiliser has been based on lime plus the four elements N, P, K and S. The carbon dioxide emissions from fertiliser, uses the data presented by Wells (2001). Over 90% of the carbon dioxide emissions from lime are on reaction with the soil. These figures are presented in Table 14.

Agrichemical emissions are based on emissions of 0.06 $kgCO_2/MJ$. This is a combination of fuels used in the production process including diesel at 0.08 $kgCO_2/MJ$, gas at 0.05 $kgCO_2/MJ$ and electricity at 0.04 $kgCO_2/MJ$.

Using the data presented by Wells (2001) the emissions from capital equipment is based on 0.08 $kgCO_2/MJ$ for equipment and 0.10 $kgCO_2/MJ$ for buildings.

Table 14 Carbon Dioxide Emissions from Mining, Manufacturing, Packaging and Distribution of Indirect Inputs

	CO_2 ($kgCO_2$/kg element, ai or m^2)	CO_2 ($kgCO_2$/MJ)
Fertiliser		
N	3.0	0.05
P	0.9	0.06
K	0.6	0.06
S	0.3	0.06
Lime	0.4	0.72
Agrichemical		
Herbicides (Glyphosate & Paraquat)	33.0	0.06
Herbicides (excluding Glyphosate & Paraquat)	21.7	0.06
Herbicides (non specific)	30.1	0.06
Insecticide	21.7	0.06
Fungicide	14.7	0.06
Capital		
Self propelled vehicles	12.8	0.08
Implements	6.4	0.08
Sheds	60	0.10
Offices	200	0.10

3.6.3 Carbon Tax

The calculation of an operations future carbon tax is based on the rate of \$25/t CO_2. The Government has indicated that when the tax is introduced in 2008 it will be set at the world price of carbon but capped at \$25/t CO_2.

The carbon dioxide emission indicators calculated in this project are for total emissions from extraction through manufacture, transport and end use of each input. Not all of these emissions will be captured by the NZ Governments carbon tax, so it is not possible to simply multiply the carbon emission indicator by \$25 to calculate the potential tax liability.

Taxable carbon emissions from liquid fuels have been calculated using the direct emission coefficients shown in Table 13 and their respective consumer energy contents shown in Table 12. For example diesel which has a direct emission coefficient of 74.1 gCO_2/MJ and a consumer energy content of 35.4 MJ/l emits 2.6 kg CO_2/l and at \$25/t CO_2 will attract a carbon tax of \$0.066/l (7¢/l) or approximately a 10% increase in cost.

The primary energy content of each fuel is not used to calculate the likely carbon tax liability as it includes an allowance for extraction, refining, and transport, almost all of which, excluding a little road transport in NZ, will not attract a carbon tax as it occurs outside NZ.

To calculate the impact of a carbon tax on the electricity sector total marginal carbon dioxide emissions, Table 13, were multiplied by the appropriate consumer or primary energy unit.

While the generation of electricity from hydro power has zero carbon dioxide emissions and is consider 100% efficient, the use of gas and coal fired fuel sources in the North Island creates the electricity sectors carbon emissions. The carbon tax is likely to add \$0.011/kWh or approximately a 17% increase in cost (excluding line charges).

This study assumed that the carbon tax will have a negligible impact on the carbon dioxide emissions from the indirect energy sources. Almost all fertiliser and machinery is imported into the country and so the emissions from these sources during extraction, manufacturing and shipping will not be captured by the NZ carbon tax. Machinery and buildings constructed from NZ manufactured steel will also not be subject to a carbon tax as NZ Steel has a Negotiated Greenhouse Agreement (NGA) which will exempt them from the tax if they achieve world's best practice.

The only major indirect input likely to be subject to the carbon tax will be NZ produced urea by Petrochem at Kapuni. Urea production has a carbon dioxide emission coefficient of 3.0 kgCO_2/kgN (Wells, 2001). Of this 0.4 kgCO_2/kgN is associated with indirect inputs which for the reasons described above can be excluded from the tax calculation. At 2.6 kgCO_2/kgN the carbon tax will add \$65/tN or \$30/t urea. This will potentially increase the cost of urea by 8%. Approximately 50% of the urea used in NZ is imported and will not be subject to the carbon tax. Across the whole fertiliser industry the carbon tax will add approximately 0.5% to costs (Dr Hilton Furness per. comm.). Due to the low fertiliser cost increase from an industry perspective no emissions from indirect inputs have been included in the carbon tax calculations.

4.0 RESULTS

4.1 Production Statistics

Most of the energy indicators are based on cropping area. Unlike dairy farming or many orchards where there is only one significant output, arable and outdoor vegetable operations have multiple crop types. These multiple crop types and the farms ability to relatively easily change the crop mix from season to season makes it extremely difficult to accurately calculate and track energy indicators based on yield. As shown in Table 15 the arable farms A1, A2, A3 and AV grow between 6 and 13 different crops. When calculating arable total energy use on a yield basis it was necessary to assume that the inputs were the same for each crop type.

The vegetable operation V1 had three crops making it simpler to track the energy inputs by crop type. For two of the surveys V2 and V3 the onion crop was separated from the rest of the operation during data collection. Fuel use, which was not tracked by crop type, was allocated to each crop on a proportional basis of the area planted.

Table 15 Crop Mix and Production Statistics

Farm	Crop type (percentage of area)	Yield (t/ha)			
		Wheat	Barley	Onion	Potato
A1	wheat 32%, white clover 21%, ryegrass 15%, barley 13%, radish 7%, tall fescue 7%, peas (seed) 4%, cabbage seed 2%	6.7	7.7	-	-
A2	barley 36%, wheat 25%, peas (seed) 15%, white clover 12%, ryegrass 6%, linseed 5%	4.3	6.2	-	-
A3	milling wheat 22%, maize silage 14%, oat silage 14%, peas process 10%, barley 10%, grass silage 5%, peas seed 5%, radish 5%, barley silage 5%, grass seed 4%, ryecorn green feed 3%, lucerne 2%, phacelia 2%	7.8 (straw, 5.7)	9.8 (straw, 4.4)	-	-
AV	barley 45%, pumpkins 20%, onions 17%, cauliflower 11%, cabbage 6%, silverbeet 1%	-	4.7	25	-
V1	onion 40%, potato 54%, lettuce 6%	-	-	55	50
V2	onion 100%	-	-	58	-
V3	onion 100%	-	-	65	-

Typical yields of arable crops in New Zealand not included in Table 15 are:

Cabbage seed	600 kg/ha	Peas (seed)	3 t/ha
Radish seed	400 kg/ha	Peas (process)	5 t/ha
Perennial ryegrass seed	1,400 kg/ha		
White clover seed	600 kg/ha		

4.2 Crop Energy Output

The energy output from each operation is shown in Table 16. This has been calculated using the crop energy content figures presented in Table 11 and the yields in Table 15.

Table 16 Energy Output by Crop Type in MJ/ha

Operation	Wheat	Barley	Onion	Potato	Lettuce
A1	96,000	114,000			
A2	62,000	92,000			
A3	141,000	170,000			
AV	-	70,000	44,000		
V1	-	-	97,000	161,000	14,000
V2 (onion)	-	-	102,000	-	-
V3 (onion)	-	-	114,000	-	-
Mean	**99,000**	**111,000**	**89,000**		

4.3 Energy Inputs

4.3.1 Direct Energy Inputs

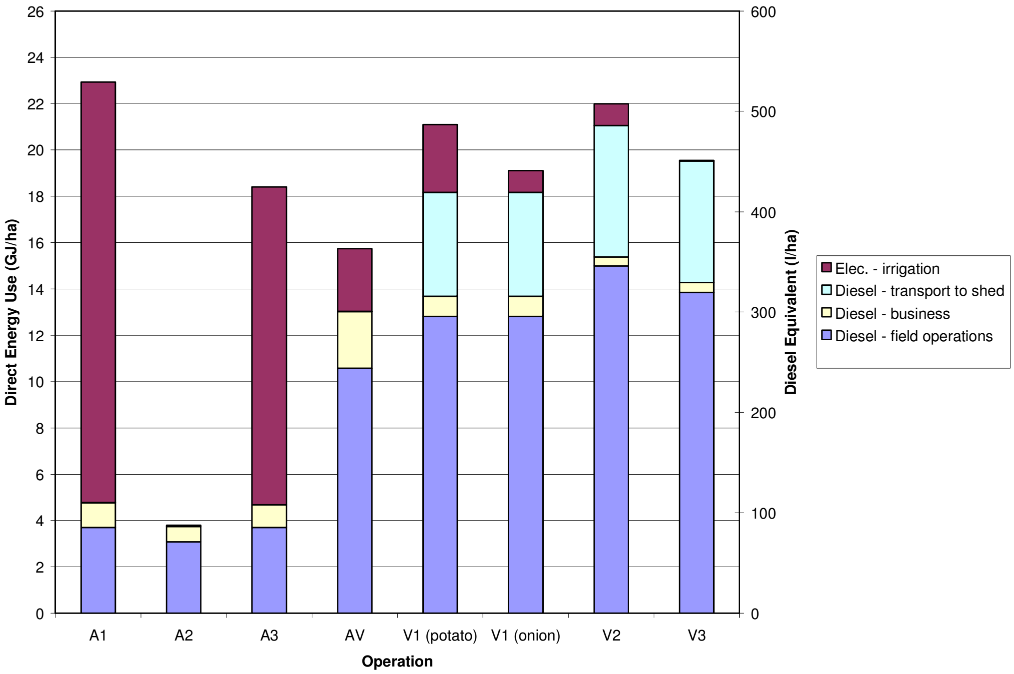
Direct energy use includes diesel, petrol, oil and electricity. In Table 17 the term diesel equivalent has been used to aggregate diesel, petrol and oil. Results for the individual operations are shown in Table 17 and Figure 1.

Table 17 Total Direct Energy and Proportions Based on Energy and Dollars

	Total Direct Energy		% Diesel based on:		% Electricity based on:	
	MJ/ha	$/ha	Energy	Cost	Energy	Cost
A1	22,950	219.80	20.9	31.0	79.1	69.0
A3	18,450	185.40	25.7	38.1	74.3	61.9
Mean	**20,700**	**202.60**	**23.2**	**34.6**	**76.7**	**65.5**
A2	3,820	54.90	98.7	99.3	1.3	0.7
AV	15,980	232.40	83.0	90.2	17.0	9.8
V1 (potato)	21,340	313.2	91.3	93.4	8.7	6.6
V1 (onion)	19,350	290.70	98.0	98.5	2.0	1.5
V2 (onion)	22,230	334.20	95.8	96.8	4.2	3.2
V3 (onion)	19,950	319.00	99.8	99.9	0.2	0.1
Mean (onion)	**20,510**	**314.60**	**97.9**	**98.4**	**2.1**	**1.6**

A megajoule of primary energy is equivalent to 0.023 litres of diesel.

Figure 1 Total Direct Energy Inputs per Hectare



On a per hectare basis the three arable operations have similar diesel inputs into their field operations averaging 3,500 MJ/ha (80 l/ha), ranging between 3,080 and 3,710 MJ/ha (71-85 l/ha). Other activities including transport to the shed and small vehicle use for business purposes add a further 900 MJ/ha or 21 l/ha.

For the two irrigated arable operations, A1 and A3, electricity use is their most significant energy input at an average of 77% on an energy basis or 65% on a dollar basis of total direct energy use.

The three vegetable operations have an average diesel input into their field activities of 13,880 MJ/ha (319 l/ha). Use of road vehicles for business adds 570 MJ/ha (13 l/ha), lubricants 290 MJ/ha (6 l/ha) and transporting crops back to a central store adds a further 5,130 MJ/ha or 118 l/ha. Total liquid fuel use averages 19,870 MJ/ha or 456 l/ha.

Table 18 shows the annual diesel use separated into field operations, business use of road vehicles, and crop transport from the field back to a central store. Diesel was the dominant fuel use so where petrol may have been used for road vehicles it was converted into litres of diesel using the equivalent energy content per litre (see section 3.2.1). The large quantity of fuel used for transporting the crop back to a central store in the vegetable production operations reflects the fact that all three operations had paddocks scattered across the whole district, unlike the arable farms which were producing off a single property.

Table 18 Annual Diesel Use by Case Study Operations

	In-field Diesel Use	Business - Utes/Cars	Transport of Crop to a Central Store	Total Diesel Use
	l/ha	l/ha	l/ha	l/ha
A1	85	24	0	109
A2	71	15	0	86
A3	85	23	0	108
Mean Arable	**80**	**21**	**0**	**101**
AV	240	56	0	296
V1	294	20	103	417
V2 (onion)	344	8	130	482
V3 (onion)	318	13	118	449
Mean Vegetable	**319**	**14**	**118**	**451**

4.3.2 Indirect Energy Inputs

Indirect energy inputs for the case study farms are shown in Table 19.

The type of arable operation, irrigated or dry land farming, did not significantly affect the total indirect inputs. Agrichemical and capital inputs were within 13% of each other. Fertiliser use produced the largest variation with A1 having extremely low inputs. The dry land operation A2 used 19% less fertiliser than the irrigated A3 operation.

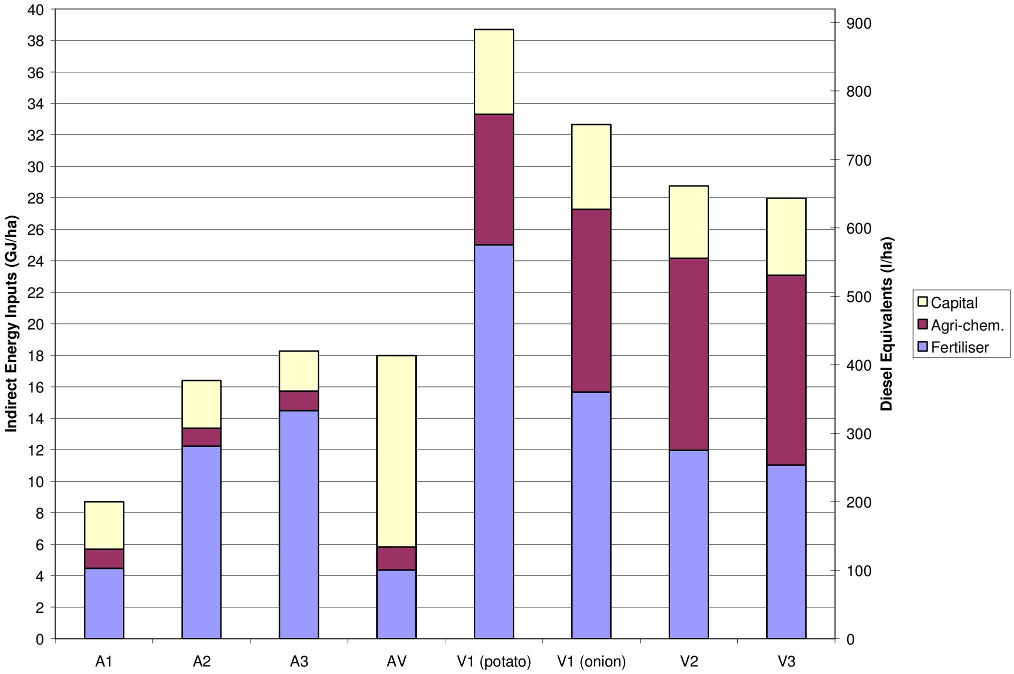
Total indirect energy inputs between the three onion operations is within ± 8% of the mean. Most of the difference was due to differences in fertiliser inputs.

Table 19 Annual Indirect Energy Inputs

	Total Indirect Energy	Percentage		
	MJ/ha	Fertiliser	Agrichem.	Capital
A1	8,700	51	14	35
A2	16,400	75	7	14
A3	18,300	79	7	18
Mean Arable	**14,500**	**68**	**9**	**22**
AV	18,000	24	8	68
V1 (potato)	38,700	65	21	14
V1 (onion)	32,200	49	36	15
V2 (onion)	28,800	42	42	16
V3 (onion)	28,100	39	44	17
Mean onion	**29,700**	**43**	**41**	**16**

Fertiliser is the single largest indirect energy input averaging 10,390 MJ/ha for arable production and 12,880 MJ/ha for onions. As seen in Figure 2 fertiliser also provides the largest variation in indirect energy inputs.

Figure 2 Indirect Energy Inputs per Hectare



Nitrogen is the single highest element making up 91% of the arable and 73% of the vegetable fertiliser inputs. As fertiliser is such a large component of the total energy input further analysis has been conducted with a larger sample of vegetable growers with the results shown in Table 20 and Table 21. The raw data for this analysis was provided by Lynette Wharfe (per. comm.) of The AgriBusiness Group from a vegetable grower fertiliser use survey in 2002.

Table 20 Fertiliser Inputs by Crop Type in kg/ha

Crop	Planting	Grower sample size	Fertiliser Input (kg/ha)			
			N	P	K	S
Brassica	Summer	1	100	40	50	70
Brassica	Winter	3	250	80	140	70
Cabbage	All year	8	190	110	130	100
Carrot		1	80	130	310	120
Cauliflower	Summer	1	160	60	90	110
Cauliflower	Winter	3	260	100	140	80
Celery	All year	2	400	160	290	150
Lettuce	Summer	2	180	80	60	30
Lettuce	Winter	6	230	110	120	50
Onion	May – Sept	22	170	130	140	70
Potato	Early & Late	14	360	190	210	70
Pumpkin/Squash	Sept – Dec	6	140	100	100	40
Silver beet/Spinach	All year	8	160	90	110	50

Table 21 Fertiliser Energy Inputs by Crop Type in MJ/ha

Crop	Planting	Grower sample size	Fertiliser Input (MJ/ha)				
			N	P	K	S	Total
Brassica	Summer	1	6,500	600	500	300	7,900
Brassica	Winter	3	16,000	1,200	1,400	300	18,900
Cabbage	All year	8	12,100	1,600	1,300	500	15,400
Carrot		1	5,400	2,000	3,100	600	11,100
Cauliflower	Summer	1	10,400	900	900	500	12,700
Cauliflower	Winter	3	16,600	1,500	1,400	400	19,900
Celery	All year	2	25,900	2,400	2,900	700	32,000
Lettuce	Summer	2	11,900	1,200	600	100	13,800
Lettuce	Winter	6	15,200	1,700	1,200	200	18,300
Onion	May – Sept	22	11,000	2,000	1,400	400	14,700
Potato	Early & Late	14	23,100	2,900	2,100	300	28,400
Pumpkin/Squash	Sept – Dec	6	8,800	1,500	1,000	200	11,500
Silver beet/Spinach	All year	8	10,200	1,300	1,100	200	12,800

From the results shown in Table 21 the average fertiliser energy input into an onion crops is 14,700 MJ/ha (170 kgN/ha). V1 is slightly above the average at 15,650 MJ/ha and V2 & V3 are both well below the average at 11,960 and 11,040 MJ/ha respectively.

4.4 Total Energy Use Indicators

By combining the direct and indirect energy use indicators presented in the Section 4.3, it is possible to calculate the total energy use for an operation. These results are presented in Tables 22, 23, 24 and 25. The average total energy input into the irrigated arable operations was 34,200 MJ/ha and 20,200 MJ/ha for dry land arable production. The average energy input for onion production was 50,200 MJ/ha and 60,000 MJ/ha for potato production (excluding postharvest grading and storage). An extremely wet 2000/01 season meant that significantly more fungicides were applied than normal to the vegetable crops in Franklin. A more typical regime (a fifth to a quarter what was applied) would reduce total energy use by approximately 12% in the onions and 9% in potatoes.

Table 22 Total Energy Indicators for Irrigated Arable Production

Item	Quantity/ha	Energy Intensity MJ/ha	Percentage
Input			
Diesel for field operations (l)	85	3,710	10.8
Diesel for business utes (l)	23	1,020	3.0
Diesel for transport to central store	0	10	0.0
Lubricants	1	30	0.1
Total liquid fuel use (diesel equivalent l)	110	4,770	14.0
Electricity for irrigation (kWh)	1,958	15,930	46.6
Electricity for packhouse/office (kWh)	*100*	*810*	-
Total electricity (kWh)	1,958	15,930	46.6
Nitrogen (kg)	129	8,390	24.6
Phosphorus (kg)	34	500	1.5
Potassium (kg)	8	80	0.2
Sulphur (kg)	61	310	0.9
Lime (kg)	287	170	0.5
Total fertiliser	-	9,450	27.7
Insecticides (kg ai)	0.3	90	0.3
Herbicides (kg ai)	2.0	850	2.5
Fungicides (kg ai)	1.3	280	0.8
Total agrichemicals	-	1,220	3.6
Tractors and implements (kg)	23	2,710	7.9
Buildings (m^2)	0.1	70	0.2
Total Energy Input		**34,150**	**100**
Total (incl packhouse/office)		34,960	
Output			
Wheat yield (tonnes)	7.2	103,030	
Wheat straw (tonnes)	5.7	29,070	
Barley yield (tonnes)	8.8	129,590	
Barley straw (tonnes)	4.4	25,080	

Overall energy ratio (OER) output: input

Wheat	3.0	Wheat and straw	3.9
Barley	3.8	Barley and straw	4.5

Energy Productivity (MJ input/tonne)

Wheat	4,750
Barley	3,880

Net Energy Yield MJ/ha (energy output/ha – energy input/ha)

Wheat	68,800	Wheat and straw	97,900
Barley	95,400	Barley and straw	120,500

Renewable Energy	10,000 MJ/ha	29%	(10,500 MJ/ha incl. postharvest inputs = 31%)
Non-renewable Energy	24,200 MJ/ha		

Table 23 Total Energy Indicators for Dry Arable Production (A2)

Item	Quantity/ha	Energy Intensity MJ/ha	Percentage
Input			
Diesel for field operations (l)	71	3,080	15.5
Diesel for business utes (l)	15	660	3.3
Diesel for transport to central store	0	10	0.0
Lubricants	0	20	0.1
Total liquid fuel use (diesel equivalent l)	87	3,770	18.7
Electricity for irrigation (kWh)	0	0	0
Electricity for packhouse/office (kWh)	*6*	*50*	-
Total electricity (kWh)	0	0	0
Nitrogen (kg)	158	10,260	50.9
Phosphorus (kg)	32	480	2.4
Potassium (kg)	23	230	1.1
Sulphur (kg)	50	250	1.2
Lime (kg)	1,677	1,010	5.0
Total fertiliser	-	12,230	60.6
Insecticides (kg ai)	0.1	30	0.1
Herbicides (kg ai)	2.8	990	4.9
Fungicides (kg ai)	0.6	130	0.6
Total agrichemicals	-	1,150	5.6
Tractors and implements (kg)	21	2,930	14.5
Buildings (m^2)	0.2	110	0.5
Total Energy Input		**20,190**	**100**
Total (incl packhouse/office)		20,240	
Output			
Wheat yield (tonnes)	4.3	61,530	
Barley yield (tonnes)	6.2	91,820	

Overall energy ratio (OER) output: input

Wheat	3.0
Barley	4.5

Energy Productivity (MJ input/tonne)

Wheat	4,700
Barley	3,260

Net Energy Yield MJ/ha (energy output/ha – energy input/ha)

Wheat	41,300
Barley	71,600

Renewable Energy	0 MJ/ha
Non-renewable Energy	20,200 MJ/ha

Table 24 Total Energy Indicators for Onion Production

Item	Quantity/ha	Energy Intensity MJ/ha	Percentage
Input			
Diesel for field operations (l)	319	13,880	27.7
Diesel for business utes (l)	13	570	1.1
Diesel for transport to central store	118	5,130	10.2
Lubricants	6	290	0.6
Total liquid fuel use (diesel equivalent l)	456	19,870	39.6
Electricity for irrigation (kWh)	78	640	1.3
Electricity for packhouse/office (kWh)	*239*	*1,940*	-
Total electricity (kWh)	78	640	1.3
Nitrogen (kg)	135	8,790	17.5
Phosphorus (kg)	134	2,020	4.0
Potassium (kg)	105	1,050	2.1
Sulphur (kg)	77	390	0.8
Lime (kg)	977	590	1.2
Total fertiliser	-	12,840	25.7
Insecticides (kg ai)	3.0	940	1.9
Herbicides (kg ai)	11.4	3,620	7.2
Fungicides (kg ai) †	35.7	7,490	14.9
Total agrichemicals	-	12,050	24.0
Tractors and implements (kg)	32	4,180	8.3
Buildings (m^2)	0.9	560	1.1
Total Energy Input		**50,140**	**100**
Total (incl packhouse/office)		52,080	
Output			
Onion (tonnes)	59	104,430	

† The 2000/01 season was extremely wet and humid in Franklin. Normal fungicide applications would be a fifth to a quarter of these amounts. This would reduce total energy use to approximately 44,370 MJ/ha.

Overall energy ratio (OER) output: input 2.1

Energy Productivity (MJ input/tonne) 850

Net Energy Yield MJ/ha (energy output/ha – energy input/ha) 54,300

Renewable Energy 400 MJ/ha 0.8% (1,600 MJ/ha incl. postharvest inputs = 3%)
Non-renewable Energy 49,800 MJ/ha

Table 25 Total Energy Indicators for Potato Production

Item	Quantity/ha	Energy Intensity MJ/ha	Percentage
Input			
Diesel for field operations (l)	294	12,810	21.3
Diesel for business utes (l)	20	880	1.5
Diesel for transport to central store	103	4,480	7.5
Lubricants	5	240	0.4
Total liquid fuel use (diesel equivalent l)	422	18,410	30.7
Electricity for irrigation (kWh)	360	2,930	4.9
Electricity for packhouse/office (kWh)	*1318*	*10,720*	-
Total electricity (kWh)	360	2,930	4.9
Nitrogen (kg)	288	18,700	31.2
Phosphorus (kg)	239	3,580	6.0
Potassium (kg)	173	1,730	2.9
Sulphur (kg)	114	570	0.9
Lime (kg)	720	430	0.7
Total fertiliser	-	25,010	41.7
Insecticides (kg ai)	3.4	1,040	1.7
Herbicides (kg ai)	1.3	530	0.9
Fungicides (kg ai) †	32.0	6,720	11.2
Total agrichemicals	-	8,290	13.8
Tractors and implements (kg)	34.4	4,460	7.4
Buildings (m^2)	1.6	930	1.5
Total Energy Input		**60,030**	**100.0**
Total (incl packhouse/office)		70,750	
Output			
Potato (tonnes)	50	161,500	

† The 2000/01 season was extremely wet and humid in Franklin. Normal fungicide applications would be a fifth to a quarter of these amounts. This would reduce total energy use to approximately 54,820 MJ/ha.

Overall energy ratio (OER) output: input	2.7
Energy Productivity (MJ input/tonne)	1,200
Net Energy Yield MJ/ha (energy output/ha – energy input/ha)	101,474

Renewable Energy	1,800 MJ/ha	3%	(8,600 MJ/ha incl. postharvest inputs = 12%)
Non-renewable Energy	58,200 MJ/ha		

For the irrigated arable operations 61% of the energy use was direct energy, three quarters of which was electricity for irrigation. Fertiliser use made up 28% of the total energy use. In the dry arable operation these proportions were just about swapped around with direct energy use dropping to 19% and fertiliser use at 61% of the total energy inputs. This comparison is shown in Figure 3 and Figure 4.

Figure 3 Proportion of Total Energy Use for the Irrigated Arable Operations

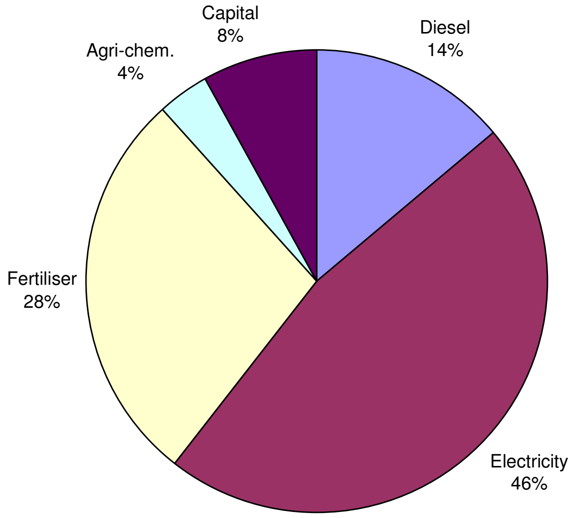


Figure 4 Proportion of Total Energy Use for the Dry Arable Operation A2

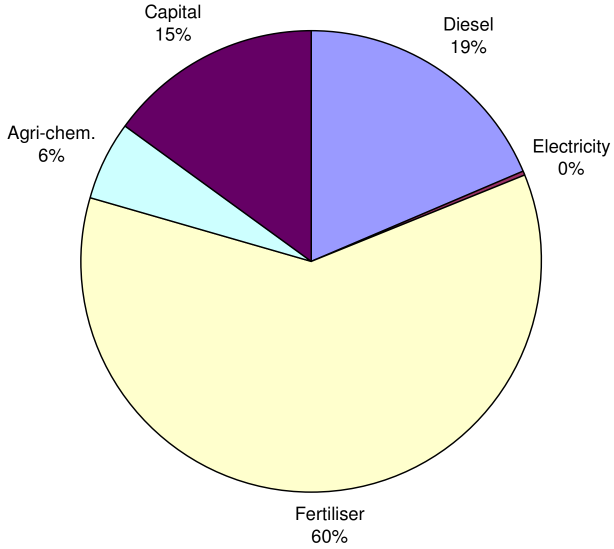
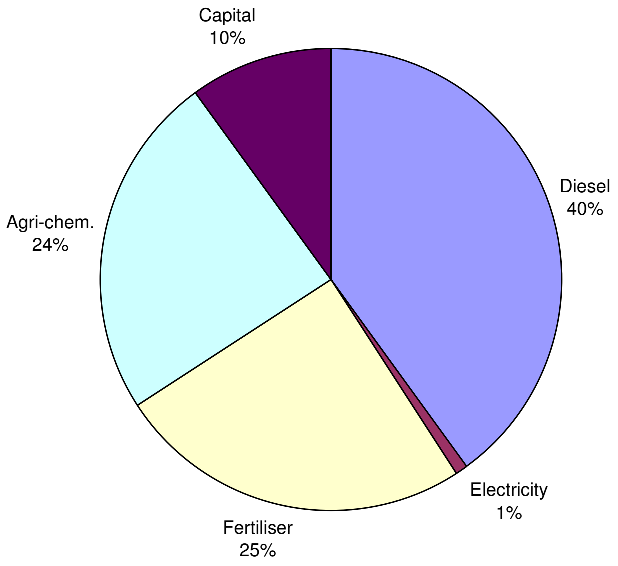


Figure 5 shows that direct energy use represents 41% of total energy inputs for onion operations, of which diesel use is approximately 97%. Fertiliser use is the next largest component followed closely by agrichemical use.

Figure 5 Proportion of Total Energy use in Onion Operations



4.5 Renewable Energy

Electricity use is the main renewable energy source used by growers. All other energy inputs are considered to be non renewable including diesel, fertiliser, agrichemicals and capital equipment. In 2000 New Zealand consumed 122 PJ of electricity, 75% of which was from renewable sources. However, based on primary energy inputs 63% of NZ's electricity is generated from renewable sources. The difference is caused by different efficiencies of generation between coal, gas, hydro, geothermal and other electricity sources.

The average renewable energy use on an irrigated South Island arable operation was 10,000 MJ/ha. This equates to 48% of direct energy use or 29% of total energy use is from renewable sources.

The North Island onion operations used an average of 400 MJ/ha of renewable energy. This equates to 2% of their direct energy use or 1% of total energy use came from renewable sources. Renewable energy use for potato production was 1,800 MJ/ha or 8% of direct energy and 3% of total energy use. The additional of the postharvest electricity for the potato grader, coolstore and office raised renewable energy use to 8,600 MJ/ha or 27% of direct energy use and 12% of total energy use.

Table 26 Renewable Energy Use

	Infield Electricity	Postharvest Electricity	Renewable Electricity † ‡	Proportion of direct energy	Proportion of total energy
	MJ/ha	MJ/ha	MJ/ha	%	%
A1	18,100	500	11,700	51	37
A3	13,700	1,100	9,300	50	25
Mean irr. arable	**15,900**	**800**	**10,500**	**51**	**31**
A2	0	0	0	0	0
AV	2,700	500	2,000	13	6
V1 (potato)	2,900	10,700	8,600	40	14
V1 (onion)	900	1,700	1,700	9	3
V2 (onion)	900	2,100	1,900	9	4
V3 (onion)	0	2,000	1,300	7	3
Mean onion	**600**	**1,900**	**1,600**	**8**	**3**

† Renewable electricity in NZ = 63% of primary energy.
‡ Includes both infield and postharvest electricity

4.6 Carbon Sequestration and Carbon Dioxide Emissions

Changes in atmospheric CO_2 levels are the result of losses when carbon is sequestered in plant material and gains through the burning of fuel. Net carbon emissions are calculated by subtracting the carbon sequestered in plants from the carbon emitted when burning fuel.

4.6.1 Carbon Sequestration

Carbon sequestered in plant material is only locked up short term, as it is quickly released when consumed. Therefore, in terms of overall climate change initiatives under the Kyoto Protocol net carbon emissions from the non-forestry sectors are irrelevant.

However, the concept of net carbon emissions and the role that carbon sequestration plays is very important. If the desired outcome is a reduction in atmospheric CO_2 then this can be achieved in several ways. Firstly by reduced energy use, which unfortunately can have severe economic impacts as most economies are closely coupled with total energy use; secondly by switching to biofuels, or alternatively increasing long term carbon sequestration.

The Kyoto Treaty only recognises carbon sequestration in trees, but by increasing carbon levels in the soil the same benefit can be achieved as well as having significant positive economic gains for the arable and outdoor vegetable sectors. These gains through higher soil organic matter levels include improved yields, reduced erosion, and lower costs by using minimum tillage practices. Due to these positive environmental effects the soil, as a carbon sink, should be considered in the mix of climate change mitigation measures.

4.6.2 Carbon Dioxide Emissions

Based on the methodology described in Sections 3.6 Table 27 shows the total primary carbon emissions in kg CO_2/ha.

Table 27 Carbon Dioxide Emissions (kg CO_2/ha)

	Diesel	Electricity (infield)	Fertiliser	Agri-chemical	Capital	Total	Postharvest electricity
A1 $_{\text{irrigated}}$	315	332	403	74	243	1,367	9
A2 $_{\text{dry}}$	248	1	1,252	68	245	1,814	0
A3 $_{\text{irrigated}}$	311	251	726	73	205	1,566	20
AV	872	50	664	88	981	2,655	8
V1 $_{\text{(potato)}}$	1,202	249	1,527	497	450	3,925	196
V1 $_{\text{(onion)}}$	1,202	17	1,169	697	450	3,535	32
V2 $_{\text{(onion)}}$	1,399	17	1,003	733	384	3,536	38
V3 $_{\text{(onion)}}$	1,308	1	930	723	410	3,371	37

4.6.3 Carbon Tax

The carbon dioxide emission values in Table 27 can not be used to estimate the impact of the proposed carbon tax to be introduced by the New Zealand Government in 2007. The figures in Table 27 are based on average primary energy coefficients, whereas the carbon tax will be levied on the consumer energy (Section 2.2.1) of fossil fuels and most likely the marginal emission of the electricity sector. Table 28 estimates the taxable carbon emissions and the potential carbon tax liability, based on a tax rate of $25/t CO_2.

Table 28 Taxable Carbon Emissions (kg CO_2/ha) and Total Carbon Tax

Operation	Diesel	Electricity †	Total	Carbon Tax ($/ha)
A1	289	1,032	1,321	$33.00
A2	227	3	230	$5.75
A3	285	820	1,105	$27.50
AV	799	175	974	$24.50
V1 $_{\text{(potato)}}$	1,108	755	1,863	$46.50
V1 $_{\text{(onion)}}$	1,108	148	1,257	$31.50
V2 $_{\text{(onion)}}$	1,282	166	1,449	$36.25
V3 $_{\text{(onion)}}$	1,199	113	1,312	$32.75

† Includes both infield and postharvest electricity

5.0 CONCLUSION

A set of energy and carbon indicators have been developed that can be used to benchmark against in the future. These figures have been incorporated into an electronic template that growers can now use to enter and track their own performance.

Baseline Data

Irrigated arable operations had a total energy intensity of 35,000 MJ/ha. Direct inputs made up 61% of the total energy use, three quarters of which was electricity for irrigation. Diesel for field operations used 85 l/ha. Fertiliser was the single largest input at 27%, almost 90% of which was nitrogen (129 kgN/ha).

The dry land arable operation had a total energy input of 20,200 MJ/ha, 60% of which was fertiliser use. Diesel for field operations required 71 l/ha.

The overall energy ratio based on wheat production (excluding straw) for the three arable operations were all within three percent of each other at an average of 3.0, i.e. 3 units of energy output per unit of energy input. The dry land operation which had the lowest direct energy input had the highest indirect energy inputs, effectively substituting irrigation energy for higher fertiliser, agrichemical and capital inputs per tonne of wheat.

The onion operations had a total energy intensity of 52,300 MJ/ha. Field operations used 319 l/ha or 27% of total energy inputs. As most vegetable operations in Franklin have more than one location around the district, as part of their crop rotation programme, a further 122 l/ha is used transporting crop and machinery between the paddocks and a central store.

In the year surveyed there was very little irrigation of the onion crop in Franklin. Electricity use made up just 5% of total energy use, three quarters of which was accounted for in the packhouse and office.

For onions a quarter of energy inputs were fertiliser, dominated by nitrogen (135 kgN/ha), which accounted for 17% of total energy. Agrichemical use was similar to fertiliser at 23%, 60% of which was fungicides. Wet weather during the season meant a higher than normal need for fungicide applications.

On a production basis every unit of energy input produced 2.0 and 2.4 units of energy output for the onion and potato crops respectively.

Renewable energy makes up half of the irrigated arable operations direct energy use at 10,500 MJ/ha or 31% of total energy use. In onion production this dropped to 7% of direct energy use or 3% of total energy use (1,600 MJ/ha). Potato production used 5,800 MJ/ha of renewable energy or 21% of direct energy inputs (9% of total energy use).

Total carbon dioxide emissions for arable operations averaged 1.6 t/ha, while onions average 3.3 t/ha.

Carbon dioxide emissions from direct energy inputs that will be subject to a future carbon tax were 1.2 t/ha for irrigated arable operations, 0.2 t/ha for dry land arable, 1.6 t/ha for potatoes and 1.3 t/ha for onions. At a tax rate of $25/t CO_2 this will cost $30/ha, $5/ha, $40/ha and $33/ha respectively.

Comparison with Historical NZ Data

Previous NZ arable estimates for total energy inputs were between 6,000 to 36,000 MJ/ha, with this studying finding 20,200 MJ/ha and 35,000 MJ/ha for dry land and irrigated arable operations respectively. In the previous studies it is unclear what energy coefficients were being used for various inputs.

Smith and McChesney (1979) estimated energy use in outdoor vegetable production at just 18,000 MJ/ha in contrast to this study at 52,300 MJ/ha for onions. The previous estimate was derived from Department of Statistics figures so there are no raw input quantities to compare with. The findings of this study are more in-line with overseas research.

Comparison with International Data

One of the more detailed studies was by Pimentel et al. (2002). In America, winter wheat production required total energy inputs of 15,100 MJ/ha by comparison this study found dry land arable operations required 20,200 MJ/ha. Fuel inputs into field operations were similar in both studies at around 70 l/ha. Business road vehicle use added a further 15 l/ha, although it is not clear if this was included in the American studies fuel use or a separate category they called transport. Electricity use for both was negligible at around 1%. Fertiliser accounted for almost all of the difference with higher fertiliser use in NZ, particularly nitrogen which was 13,600 MJ/ha (158 kgN/ha) compared with 5,900 MJ/ha (67 kgN/ha).

However on an energy utilisation basis the overall energy ratio (OER) (output: input) of the arable production systems in this study are ahead of the American figures at 3.0 compared to 2.5 (Pimentel et al., 2002). Wheat yields in the NZ dry land operation were 4.3 t/ha compared to 2.7 t/ha in America. An earlier study of American wheat by Pimentel (1980) found OER's ranging between 0.4 and 4.6.

Pimentel et al. (2002) also analysed potato production and at 58,000 MJ/ha is fractionally less than this studies potato figure of 59,200 MJ/ha (excluding electricity in postharvest storage). The American potatoes required 400 litres of diesel per hectare, similar to this study at 423 l/ha, although in NZ field operations required just 294 l/ha and it is not clear if transport between the paddocks and store is included in Pimentel's fuel figures. Fertiliser inputs were higher in NZ at 24,000 MJ/ha (excluding sulphur and lime) compared to 19,400 MJ/ha in America. NZ used higher quantities of fungicide although that reflects the particularly wet and humid conditions during the growing season when this study was conducted.

Like in the arable production sector potato yields in this study were higher than those reported by Pimentel et al. (2002) which has resulted in slightly better energy utilisation with an OER for potatoes of 2.4 compared to 2.2 in America.

Area for Further Analysis

To further advance this work and improve the usability amongst farmers and growers a set of generic costs should be developed for each input which would allow whole production systems to be compared on both an energy and financial basis. For example when comparing dry land and irrigated arable operations the same energy utilisation was achieved by essentially substituting irrigation energy for fertiliser, but how does this compare financially?

The intention of the project was to track the actual energy inputs of six case study farms. What become apparent was that for all but one operation systems were not in place to track inputs on a crop type basis. Improvements in tracking systems that will come with the increasing demand for crop traceability will improve the reliability of those energy intensity indicators that are based on crop yields rather then area. These advances will further improve an operations performance by helping to optimise the most economic and environmentally sustainable crop mix.

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