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The Evolution of Total Energy Inputs in the New Zealand Dairy Industry

A thesis

submitted in partial fulfilment

of the requirements for the Degree of Masters of Natural Resource
Management & Ecological Engineering

at

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by

Marcel Podstolski

Lincoln University

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In 1998, Wells (2001) conducted a national study of the total energy inputs of New Zealand dairy farms. The study demonstrated the superiority in energy efficiency of New Zealand dairy production compared to that of European farms.

Over the past decade, New Zealand's dairy industry has transformed. With the growth of the industry in nontraditional regions, as well as a significant increases in irrigation, nitrogenous fertilisers, and supplementary feeds, there has been a substantial growth in milk production driven by an increasingly commodified export market.

While the industry has experienced significant changes in the past 10 years, these changes have not yet been reflected in research. As a consequence, the impacts of these developments on the energy requirements of milk production are not yet fully documented. This study addresses that gap in data.

This study is the first comprehensive, national assessment of energy requirements of New Zealand dairy farms since 1998. In this study, the total energy inputs of 135 New Zealand farms were calculated to determine their energy intensity and efficiency. Results were compared with energy input records from 1978 and 1998. Results of this study suggest that, in

comparison with historical data, dairy farm energy intensity has significantly increased in all regions of New Zealand; energy efficiency has worsened in all but one geographical region. Despite this, New Zealand dairy farms are still more energy efficient than those of other major international competitors, which suggests the competitive advantage still remains.

This research identifies the key drivers of changes to energy inputs, and offers recommendations for reducing the energy consumption of dairy production, to safeguard against energy vulnerability, and to reduce the environmental impacts of the dairy industry.

Keywords: Energy, Fuel Consumption, Agricultural Operation, Dairy Production,

New Zealand

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Nie każdy myśli, ale każdy jada - JP Tremo

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Chapter 1

Introduction

The dairy industry is one of the most important sectors of the New Zealand economy, comprising approximately one third of the nation's export earnings (RBNZ, 2014). New Zealand's dairy industry, with its year-round pastoral systems, has a distinct environmental profile in comparison to the dairy industries of other nations, such as the United States or European nations. However, New Zealand's dairy industry is also in a period of transition and growth, towards a more industrialised model (Jay, 2007).

New Zealand's agricultural sector is comparatively highly mechanised, and New Zealand's total primary energy supply is very heavily dependent on non-renewable energy sources, although less so than many of its competitors. New Zealand over the coming years will likely face a range of pressures to increase dairy production, and changes to dairy systems are likely to occur too. A new energy survey, measuring the energy footprint of a modern intensive-pastoral New Zealand dairy farm, will help shape the changes and improvements that can be made to the dairy industry.

1.1 Why is energy important?

While energy is not a primary focus of agricultural studies, it can still be a useful and important indicator. Even a simple ratio comparing energy to land use, or energy to kilogram of product can easily and simply show the intensity of a farming system. By understanding the energy make-up and footprint, the industry can see its whole impact, the primary drivers of that impact, and the industry can make comparisons across different farming production systems, regions, and internationally.

Energy in agriculture first emerged as an important topic in the early 1970s in the United States and Europe, spurred on by the contemporary energy crises developing from the Arab and OPEC nations (Pimentel et al., 1973). In New Zealand, studies on energy in agriculture were also closely linked to the 'Think Big' era, alongside many other energy initiatives as the vulnerabilities of New Zealand's energy demands were demonstrated by the global energy crises (McChesney, 1991; McChesney, Sharp, & Hayward, 1981; Pearson, 1977; Wright & Baines, 1991). Thus far in the 21st century, energy prices have seen greater volatility than in

previous decades. Longer-term issues of sustainability and resource usage are increasingly important. Within New Zealand's industrial-commercial dairy industry, environmental issues are framed by their relationship to productivity and outputs. Energy has not made its way within this knowledge framework before, which has instead been focused on water and nutrient issues (Jay, 2007).

Nevertheless, the dairy industry has been able to adapt some environmental concerns into the way that it manages dairy farms, especially where those concerns reflect commercial or productivity benefits. There is, it can be assumed, room for energy issues to also enter into the discourse, especially if energy can be framed in a way that appeals to the productivity of farms. However, there are also benefits to non-farmers, at the policy and governmental levels. While farmers should see benefits as well as some responsibility for assisting in the gathering of data, New Zealand's total direct agricultural energy consumption has increased by 52% between 1990 and 2010, with a peak in 2007, a drought year (MED, 2012).

By comparison, New Zealand's total direct energy consumption over the same period increased by 31%. Agriculture's share increased from 3.7% to a 2007 peak of 5.1%. By comparison, most European nations have seen energy shares fall both as a proportion of the total, and in real terms. Australia, Canada, and the United States have seen stable or minor increases (OECD, 2013).

1.2 New Zealand's Competitive Advantage

New Zealand has traditionally had a competitive advantage in dairy production in energy terms. Wells (2001) and Saunders, Barber, and Taylor (2006) have provided clear examples where New Zealand's energy efficiency in production has given a strong advantage to New Zealand products against major international competitors, such as the United Kingdom, United States, and the European Union.

While New Zealand has traditionally been a low-input, low-production farming system, this research explores the impact that the drive for increased production in an increasingly competitive global market for dairy products has had on the energy inputs required in New Zealand farms (MacLeod & Moller, 2006).

1.3 Opportunities for Energy Efficient Dairy in the Global Market

While New Zealand has held an advantage against major international competitors in the past, the changes seen in recent years to the dairy industry, particularly the large scale expansion of the dairy industry into non-traditional dairying regions in New Zealand, may suggest that this competitive advantage may be under threat.

Much of the growth in the New Zealand dairy industry in recent years has been driven by increasing demand from China (RBNZ, 2014). In 1992, the Chinese market represented less than a percent of the total value of New Zealand's dairy exports; by 2012, the Chinese market had grown to be the largest single destination for New Zealand dairy products, and the Chinese market accounted for nearly 25% of exports (Statistics New Zealand, 2013). The demand from China for dairy products is not limited to New Zealand however, and while New Zealand has held an early lead in the Chinese market, the scale and demand that that market offers makes it highly attractive to other dairy producers. The Chinese market has, however, been reported to be willing to pay a substantial premium, an additional 25%, for dairy products that are environmentally conscious, with lower energy consumption and greenhouse gas emissions, and marketed as such (Miller, Driver, Velasquez, & Saunders, 2014).

The Indian market is one where New Zealand has played a relatively small role. However there exists a huge potential for demand for dairy products, by as much as three times larger than China's, as India's population urbanises and becomes more wealthy (RBNZ, 2014). The Indian market is also reported to have a higher willingness to pay for environmentally conscious products, with low energy and greenhouse gas emitting products having a 38% price premium (Miller et al., 2014).

Both the Chinese and Indian markets represent greater opportunities for energy efficient dairy production, therefore, if this attribute is properly marketed. New Zealand may struggle to compete in sheer volume in the future, as other nations seek to access these markets. However, if New Zealand's energy efficiency in dairy products can be maintained, then that may allow for a strong competitive advantage in these key developing markets.

Chapter 2

Literature Review

This review of literature is structured around the two key studies on total energy inputs and the New Zealand dairy industry, those by McChesney (1979) and Wells (2001). Further to these two studies, the history of energy analysis from inception to the mid-1990s is covered, followed by the comprehensive study conducted by Wells. From then on, this chapter considers other developments in the New Zealand dairy industry since Wells' study, as well as relevant agricultural energy studies that demonstrate continuing interest in this field.

2.1 Energy Analysis

2.1.1 Theoretical Foundations

The study of energy is a relatively recent occurrence, with energy studies only being developed from the mid-1970s onwards (Peet & Baines, 1986). Prior to the first energy crisis in 1973, there was almost no research conducted on energy (Pearson, 1977). Much of the impetus for energy studies came from the OPEC oil crisis of 1973/1974, however the role of energy and its interdependence can also be interlinked with the development of concepts of ecology, and the growing understanding of energy flow within systems. One of the earliest examples of energy and ecology linked energy and agriculture, for example Pimentel et al. (1973). Initially, energy studies coalesced around a theoretical framework called Energy Analysis, as a branch of analysis separate from economic analyses and drawing from a wide range of disciplines and paradigms (Peet & Baines, 1986). Possibly the earliest definition of Energy Analysis was established in 1974, which defined "energy analysis as the determination of the energy sequestered in the process of making a good or service within a framework of an agreed set of conventions" (Nilsson, 1974, as cited in Peet & Baines, 1986). At the same time, the limitations of economic analyses regarding incomplete information in the face of resource scarcities were recognised, and "it was agreed that the price system did not always embody sufficient information to make decisions, or to make them in adequate time" (International Federation of Institutes for Advanced Studies, 1978). One of the limitations of such a definition is that it is limited in its temporal scope. There is no acknowledgement of time scale in such a definition, and instead the analysis is conducted in a static timeframe, a snapshot of a particular time period. The broadness of such a definition however gives sufficient scope to

incorporate a wide range of activities within a process. The definition of 'process' was also a point of contention, and energy studies co-developed with systems theory and systems thinking. Energy remained not as the product, but took its definition from physics and the Laws of Thermodynamics, although in practical terms energy is defined as 'the ability to do work'. Thus, the physical term of energy, the ability to do work, can be ascertained. Thus, the universality of energy as a common denominator across all systems made it a logical medium for analysis within systems; informing the structure, function and dynamics of real physical systems at all levels. Energy analysis used systems at global, national, regional, and smaller levels to conduct analyses to study energy accounting, energy requirements, structural patterns of energy use, efficiencies of energy uses, and energy flows as a means for linking ecological and economic systems together (Peet & Baines, 1986).

The theoretical foundations in the Laws of Thermodynamics and the definition of energy as the ability to do work were combined with the concept of embodied energy. Embodied energy is concept of all the energy that has been consumed or sequestered into processes or systems that then create further goods, processes, or systems which are then measured. This is a reflection of the ecological concepts of trophic structure, and also draws from systems theory, specifically concepts such as system-wide interdependency. These further draw from concepts such as Leontief's theory of structures, namely that "dependence and independence, hierarchy and circularity (N multi-regional interdependence) are the four basic concepts of structural analysis" (Leontief, 1963). These structural analyses, originally within the field of economics, rely on a series of coefficients in order to function correctly, but can be used to create predictive models.

Leontief's input-output analysis concepts were further developed for Energy Analysis by combining them with the concept of the conservation of energy from the Second Law of Thermodynamics. Thus, embodied energy is conserved throughout circularity. Processes and systems are dependent on those that came before in a hierarchy, and conservation of energy throughout these can be used to track energetic flows. From these concepts, the idea of energy intensity (the embodied energy per unit of production) was developed.

2.1.2 Historic Energy Surveys in New Zealand

From the early 1970s, energy usage in agriculture began to be studied in New Zealand, chiefly by the NZ Energy Research & Development Committee and the NZ Dairy Research Institute.

Both organisations no longer exist, and the disestablishment of the NZERDC in 1988 seems to have spelled the end for the energy surveys. The early studies were motivated by New Zealand's reliance on agricultural products as the most important sector of the economy, and focused on energy dependence and the comparative energy efficiency of agriculture (McChesney et al., 1981). However, the existence of these surveys allows for the development of a time series of dairy energy surveys to be compiled, showing how the dairy industry's energy consumption has evolved over decades.

As with the rest of the world, energy was not studied in New Zealand prior to the first energy crisis of 1973. Data collection for the energy sector was similarly slow to develop, with electricity data being first collected in the late-1960s, petroleum fuels in 1974/1975, and gas not until 1980/1981 (Wright & Baines, 1991).

The history of the New Zealand government's approach to energy planning was broadly described by McChesney as follows:

Phase 1	Up to mid-1970s	Government control and responsibility, ad-hoc planning
Phase 2	Mid-1970s to mid-1980s	Government control with deliberate "planning" approach
Phase 3	Mid-1980s onwards	Diminished Government responsibility and a progressive move to market-based strategies

Table 1: New Zealand Energy Strategies (McChesney, 1991)

Prior to the first energy crisis of 1973, government energy policy was to ensure the continued supply of energy in the face of rising demand, as demand for energy increased at four to five per cent per annum (McChesney, 1991). The relatively abundant national energy resources of the time (excluding oil), and New Zealand's strong agricultural exports, combined with the Government's strict regulation of the energy sector including price controls kept New Zealand in a comfortable position until the mid-1970s. In fact, there was little data kept or collected by the government, and many sources were ad-hoc and decentralised (Wright & Baines, 1991). The Ministry of Energy Resources was formed in 1972, followed shortly by the New Zealand Energy Research and Development Committee (NZERDC). In 1978, the Government published its first ever energy strategy, and while most of the focus was on the first goal of

that strategy, namely reducing New Zealand's dependence on imported oil, other goals included energy efficiency, diversification, and energy planning. The creation of governmental bodies and strategies was responsible for the flurry of research activity in New Zealand through the 1970s and into the early-1980s (McChesney, 1991). By the mid-1980s however, as globally rapid declines in the price of oil and the expensive projects the Government had embarked on to achieve oil independence became increasingly burdensome, the Ministry of Energy and NZERDC were disbanded and merged into the Ministry of Commerce by 1988. Subsequently, energy research was reduced to almost nothing, with only a handful of papers published between 1984 and 2000.

Year	Literature Reviews	Energy in Agriculture (specific sectors or inputs)	Energy in Agriculture (overviews & reviews)	Farm Energy Surveys
1976	2		1	
1977	3	4		
1978		5, (1), (2)		6
1979		(3)	8, 9, 10	7, (4), (5)
1980	(7), (9)	(8), (10)		(6)
1981		(12), (13), (14), (15), (16)		(11)
1982			11	
1983		12, 13		
1984				
1985				
1986				
1987	14			
1988		15		

Table 2: New Zealand Agricultural Energy studies, 1976-1988. Numbers in brackets indicate unpublished reports (see appendix), prepared as background papers. The peak of research outputs in the years 1978-1982 can clearly be seen.

Developments in the late 1970s

Pearson (1976) largely introduced Energy Analysis to New Zealand with a report outlining the scope and development, and the need for energy analysis for New Zealand. Pearson identified the important role of energy analysis and food production, and mentioned the agricultural sectors which had been identified for energy analysis, including dairy. Pearson and Corbert (1976) provided the first outline of New Zealand's total energy use for the entire agricultural and forestry sector. In general, this outline was constructed from fuel import and electricity generation statistics, however the very low application of nitrogen fertilisers (approximately

5% of energy requirements) was noted. Brown and Pearson (1977) compared NZ to Australia, UK and USA.

Dawson (1978) collected from international literature and national sources the first set of energy coefficients, energy values of inputs, for use in NZ. Dawson's report was initially produced as a preliminary report in 1976, and later underwent two revisions in 1977 and 1978. Energy coefficients were either drawn from international sources and adapted to New Zealand by accounting for transport costs, or, more often, surveys of New Zealand manufacturers were undertaken to determine the energy requirements of domestically produced inputs. This process was aided by the low number of domestic producers, for some inputs there were only one or two producers. Dawson identified a number of limitations to the energy coefficients developed, which included a lack of readily available data, reliance on overseas data, and incomplete coverage of manufacturers and products (Dawson, 1978, p. 16). Thus, Dawson recommended that the estimates be considered as a minimum amount required.

2.1.3 McChesney 1979

One of the key New Zealand studies of energy use in the dairy sector was McChesney's pilot study on town milk supply farms in central Canterbury, conducted prior to an expected wider survey of North Island farms. Twelve farms were selected, based on the expectation of the farmers' ability to provide the required information. As a pilot study, there was no attempt to make the sample a representative one, however it was determined that the surveyed farms tended towards larger and more productive farms. These farms represented around 8% of the town milk suppliers, but 14% of the production. Eleven of the twelve farms were irrigated, and most farmers kept their herds in confinement on-farm over winter. The farms had non-dairy elements, typically including beef production or cattle stud farming. Several farms in the survey also undertook arable cropping. As town milk supply farms, these farms were required to produce milk year-round, rather than seasonally as factory-supply farms would tend to do. This meant that direct comparisons between town milk supply farms and factory-supply farms could not be made.

McChesney's study was based on interviews conducted in late 1977 and early 1978, using data for the 1976/77 dairy season. Direct, indirect, and capital inputs were considered, although capital inputs were not distinguished as such from indirect inputs. There were limitations in data collection as "numerous minor indirect" energy inputs were not accounted for

(McChesney, 1979, p. 4). A justification for this was the limited time and pilot study nature of the survey. It may also have been a product of the early nature of energy analysis in New Zealand. A further limitation was fuel data, as fuels made up a significant proportion of total energy on farm. Farmers tended to buy fuels in bulk, and then use those fuels for farm and non-farm use. Petrol was a much larger component of the fuel used on farms, than would be expected in modern farms, with farms having both tractors and heavy trucks run on petrol, alongside cars. McChesney was not able to ascertain from the surveyed farmers a consistent basis for these usages. Electricity data was provided directly by the local electricity boards.

Fertilisers were not a major input to the farms, however irrigation as previously mentioned was common to all but one farm. One farm applied nearly half of all nitrogen fertilisers consumed by the whole sample, with the remainder using small quantities of superphosphate and nitrogen fertilisers. This appeared consistent with the North Island survey, where fertiliser use was much more prevalent in a small number of high producing farms.

Irrigation was mostly electric, although three farmers also had diesel pumps. Electricity use for other inputs was quite low, with McChesney noting that there were old and inefficient fuel inputs that could be replaced with electric ones, for instance in irrigation and dairy sheds.

Supplementary feeds were a substantial contributor to total energy inputs, as the milk supply farms were required to produce milk year round, and higher winter milk prices gave farmers more incentive to add supplementary feeds.

McChesney found that the total energy inputs required were 9.1 gigajoules per hectare, while inputs per litre of milk were 1.7 megajoules per litre. This corresponds roughly to total energy inputs of 21.1 megajoules per kilogram of milk solids. McChesney estimated that his energy calculations likely understated the total as a complete inventory was not taken, however, this may have been balanced somewhat by the tendency to select larger farms for the survey.

McChesney's pilot survey was not followed up with a national survey. While there was considerable interest in the role of energy in agriculture, this was focused on the agricultural sector as a whole, as seen in studies such as Chudleigh and Greer (1984); McChesney et al. (1981); Smith and McChesney (1979); Thompson (1982). A comprehensive survey of the dairy industry specifically does not appear to have been undertaken. Energy coefficients were often significantly different to those used in Wells (2001) and other studies.

2.1.4 Research in the 1980s

The second oil shock of the late 1970s altered the direction of energy analysis in a reactionary way. The immediate research focus in New Zealand was on ways to address the nation's oil vulnerability. Chudleigh, Young, and Brown (1979) drew on earlier pilot studies to analyse New Zealand agriculture's vulnerability to oil price increases, and specifically looked at areas such as transport. While it found that New Zealand's vulnerability was relatively small, the lack of available data was apparent. After McChesney's (1979) pilot study, a more detailed investigation into fuel consumption on North Island dairy farms was conducted. This survey, also conducted by McChesney, covered 33 North Island factory supply farms. The oil shock of the late 1970s was the immediate driver for the survey, as the survey only collected the direct inputs and explicitly excluded indirect inputs (McChesney, 1980). As such, the survey does not represent a survey of total energy inputs, as direct energy inputs were estimated to only comprise around 30% of the total at the time (McChesney, 1980). Internationally, there was a split in energy analysis between an "eco-energetic" school of energy analysis interwoven with ecology, that tracked energy flows through a industrial system following the methodology of energy flows in ecology, and a "sequestered" energy analysis school, which focussed on energy embodied in products. (Fluck & Baird, 1980, p. 42). Pimentel (1980) work developed comprehensive energy coefficients and methods for the "sequestered" energy analysis school of thought, and research in New Zealand followed that pattern.

In the early 1980s, there was a flurry of research, including projections for New Zealand's agricultural energy trends (McChesney et al., 1981); the first model of energy use (Thompson, 1982); and broad attempts to categorise energy consumption across the nation, for example: Miller and Vickers (1982) analysis on the dairy processing industry's energy consumption; McChesney, (1983a, 1983b) calculating demand for liquid fuels, and electricity consumption of irrigation; Clark (1983); Sims and Henderson (1983) identifying specific areas of energy conservation; and Chudleigh and Greer (1984); Patterson (1984) revising the national perspective of agricultural energy usage. By the mid-1980s however, interest in energy analysis waned, with few other publications arising. At the same time, the agricultural sector underwent de-regulation, and government involvement in the sector withdrew (PCE, 2004).

In the 1990s, there was comparatively little agricultural energy research conducted in New Zealand, with a tendency for energy research as privatisation and fragmentation of the energy sector diverted focuses. However, the issue of sustainability in agriculture and in energy

emerged, with work such as Nguyen and Haynes (1995) analysis of different farming models in Canterbury a precursor for a new generation of energy research with sustainability as a driver and focal point.

2.2 Wells – Total Energy Indicators of Agricultural Sustainability: Dairy Farming Case Study

Wells (2001) development of a comprehensive methodology and his subsequent analysis of the on-farm energy intensity of dairy farms was intended to form the baseline and define the shape of agricultural energy analysis in New Zealand. The study was originally proposed in consultation with the Parliamentary Commissioner for the Environment, and the research was conducted for the then Ministry of Agriculture and Forestry (MAF).

Wells' purpose was to determine the baseline for energy as a key indicator for agricultural sustainability. Within that, Wells developed the following as key indicators for dairy energy intensity:

- Milk solids production per effective milking hectare (production intensity)
- Total primary energy requirement (direct, indirect and capital energy inputs) per effective milking hectare (energy intensity)
- Overall energy ratio (total primary energy input divided by calorific energy output)
- Proportion of renewable energy within the total primary energy requirement.
- Total carbon dioxide emissions per effective milking hectare (gross emission intensity)

Wells defined energy through the term 'total primary energy input', "implying that all forms of energy, measured at the source (i.e. at oil & gas wells, power stations, etc.), required for farm operation are included. For example, *direct energy* (fuel & electricity), *indirect energy* (for the production of consumables such as fertiliser & supplementary feeds), and *capital energy* (for the manufacture of vehicles & buildings). The exception is "free" solar energy for pasture and crop growth, which is excluded. Therefore total primary energy includes energy losses during conversion processes such as oil refining and electricity generation" (Wells, 2001, p.1). The definition of these three forms of energy, direct, indirect, and capital, had already been used in New Zealand in earlier studies, such as Brown and Pearson (1977);

Chudleigh and Greer (1984); McChesney (1979); and Patterson (1984). Within this definition, Wells was able to set a boundary around the farm that included the above inputs, while ending at the 'farm gate', the point where the products left the farm properties permanently.

The study involved the survey of 150 farms around New Zealand, the first batch of data from 96 farms being collected in 1997/1998. The following year, an additional 54 farms were used to mature the data set with larger irrigated farms as well as reaching the target number. However, the number of farms surveyed comprised only around 1% of the total national number of dairy farms at that time, and there were some significant regional representation differences between surveyed farms and the proportion of national farms at the time. Most notably, Canterbury farms made up 16% of the surveyed farms, with the second collection of survey data more heavily targeting the South Island, although Canterbury dairy farms only accounted for 3.8% of the national total. Likewise, Auckland/Waikato farms were under represented, the region providing 42% of the national total, but only 28% of the surveyed farms. This, it was hoped, would correct for the difference in farm size and also provide more information on the impact of irrigated farms. Wells found that the key areas for farm energy improvement were fertiliser use and irrigation. Within this, differences between types of irrigation were also cited as important. Changes in both of these factors, and in particular the expansion of larger scale, more fertiliser- and irrigation-intensive dairy farming in Canterbury had caused energy use per hectare to double, although energy per produced kilogram of milk solids remained similar.

Indicator	Northland	Waikato	Bay of Plenty	Taranaki	Lower North Island	West Coast-Tasman	Marlborough-Canterbury	Otago-Southland	Weighted National Average
Farm Size (ha)	115	72	105	73	104	128	175	137	86
Herd size (cows)	259	201	292	240	276	248	470	328	234
Milk Production (tonnes milk solids)	69.4	57.9	85.6	75.2	83.4	69.4	171.8	127.2	69.3
Stocking Rate (cows/ha)	2.2	2.8	2.8	3.3	2.7	1.9	2.7	2.4	2.8
Energy Intensity (GJ/ha/yr)	14.5	17.9	18.5	18.6	15.3	16.9	36.5	18.6	18.2
Overall Energy Ratio	0.64	0.59	0.60	0.47	0.50	0.81	0.99	0.54	0.59

Table 3: Key Production and Energy Indicators from Wells (2001)

The farms themselves could differ in their energy use by an order of magnitude, with the lowest energy use being recorded by a Northland farm, averaging 5.8 GJ/ha/yr, versus the highest energy use, recorded by a large irrigated Canterbury farm which used 65 GJ/ha/yr. Regionally, Canterbury farms reported much higher energy use per hectare, averaging 35 GJ/ha/yr, whilst other regions reported energy intensities around 20 GJ/ha/yr. On the other hand, Canterbury's produced milk solids were higher, but by a smaller difference. Renewable sources formed a relatively low proportion of energy used on farms, providing only 15% of the total energy used, highlighting the reliance of agriculture on fossil fuels, and the vulnerability to external price and supply issues. Wells further found that energy was not a predictor of output, rather, farms with very similar production outputs could have very different energy intensities. Wells developed an Overall Energy Ratio (x units of energy input for one unit of calorific energy output in the milk) for a 'National Average farm' (the weighted average of the surveyed farms).

Wells found that for the 'National Average', while energy per hectare had doubled in the previous two decades, production intensity had also increased by a similar amount, leading to only a 10% increase in Overall Energy Ratio. However, of Canterbury's farms, 92% had Overall Energy Ratios above the 'National Average farm' (Wells, 2001, p. 71). Likewise, while the 'National Average' farm's Overall Energy Ratio was lower than any overall energy ratio reported by international sources (0.59 for the 'National Average farm', versus 2.8 for United

States farms, and 0.67-2.4 for European farms), individual farms exceeded international overall energy ratios (Wells, 2001, p. 72). Wells found that there was a weak correlation between fertiliser application and milk production intensity, while there was a positive correlation between fertiliser application and energy intensity. Thus, there was a weak correlation between fertiliser inputs and overall energy ratio, and subsequently a risk of worsening the efficiency of production, expressed by the inverse, an increase in the overall energy ratio.

The regional overall energy ratio disparity led Wells to caution that there could be substantial increases in New Zealand's overall energy ratio if the majority of future conversions to dairy farms occurred in Canterbury. Wells also found that the drought conditions in 1997/1998 led to higher irrigation use than normal, which in turn significantly influenced energy use, with the drought in Canterbury increasing electricity use by 15-20%. These factors led Wells to recommend that energy indicators be included in the monitoring of sustainability in agriculture in the future, with annual energy monitoring and tracking of the overall energy ratio providing data on New Zealand's sustainability and comparative economic advantage.

2.3 Dairy Industry Changes in the 2000s

In the time after Wells, the dairy industry in New Zealand continued to evolve. New Zealand's dairy industry underwent a period of consolidation, as Fonterra emerged as a near-monopoly of an increasingly commoditised industry. At the same time, New Zealand had some of the lowest governmental intervention in the OECD, with the government encouraging a market-centred approach with little strategic involvement (PCE, 2004). In three key areas, hectares farmed, cow population, and stocking rate, large increases, of 12%, 34%, and 19% respectively, were observed in the decade either side of Wells' study (PCE, 2004, p. 36).

Increasing prices for milk and milk solids are a major incentive for increased dairy production. While year-to-year there have been fluctuations, there was a steady inflation-adjusted increase from the early 1990s through the first decade of the 21st century, with real prices increasing by around 1% per annum on average (Pangborn, 2012, p. 16). In this context, other major changes to the dairy industry were drawn from the literature for investigation.

2.3.1 Farming Systems

The mid-2000s saw the development and adoption of a system of dairy farm classifications by industry body DairyNZ. This classification only compares the amount of supplementary feeds used on farm, used to increase production in New Zealand's seasonal and pastoral dairy farms. However, this classification has become a common measure for dairy farms nationally.

The classification placed farms into one of five categories, based on the total usage and timing of supplementary feeds (Table 4). This classification uses only a single variable, measuring the importation of feed on to the farm. The simplicity of the single variable approach allows for a level of universal comparison between different regions and climatic conditions (Hedley et al., 2006). However, other dairying variables, such as once-a-day milking, indoor feeding, or fertiliser applications are excluded from this classification system. There do seem to be correlations between the production system and other factors, for instance feeding pads should be more developed in System 5 farms than in System 1 farms.

Unfortunately, there is not currently a way to distinguish the extent of a correlation between the system classification and other factors. However, an indication of these correlating factors is given in Hedley et al. (2006), with example farm key performance indicators increasing in correlation with increased system classification. For instance, the example key performance indicator for "electricity, milk shed" is listed as \$100 of expenditure per hectare for a System 1 farm, increasing to \$144 for a System 5 farm. Likewise, the vehicle costs increase from \$95 to \$215. On the other hand, fertiliser applications decline across higher System levels, presumably accounting for the shift towards imported feed. Thus, it can be assumed that there are correlations between System levels and other intensity factors.

System 1	An all-grass self-contained dairy system, <4% imported feed.
System 2	4-14% feed imported to supplement or for grazing off for dry cows.
System 3	10-20% feed imported, to extend lactation (typically autumn feed) and for dry cows.
System 4	20-30% feed imported, at both ends of lactation and for dry cows.
System 5	30-55% feed imported, used all year throughout lactation and for dry cows.

Table 4: Description of Farm Classification Systems, adapted from Hedley et al. (2006)

There has also been a marked change in recent years between different systems. (Greig, 2009) found that between 2000-02 and 2009-10, System 5 farms increased by 300%, albeit from a small base, while System 4 farms increased by 63% to take an 18% share of total farms. System 3 farms increased by 111% to grow to a 36% share, the largest system in use. By comparison, System 1 farms, which had a 41% share of the total in 2000-02 shrank to just 10% of the total by 2009/10, a 75% decline (. Hedley et al. (2006) reported that the increased system level was matched by an increased return on assets and profitability, with System 5 farms achieving as much as a 50% higher return on assets than System 1 farms.

The available literature does not appear to provide justification for the adoption of this particular classification. Discussions around this suggest that there may not be a publicly available justification, rather, that adoption has just been assumed by industry. The universality of the classification, as well as the simplicity of understanding and application, does give the 5 System classification advantages for adoption by industry. However, it would appear that there has not yet been an academic review of the benefits and drawbacks of this classification system. Equally, it was not possible to confirm the correlations discussed above, and as such, there remains the concern that the classification may be too narrow in its focus for accurate comparisons across different farming technologies.

2.3.2 Land Use Change

In the decade prior to Wells' (2001) study, there had been a substantial fall in the number of dairy farms¹ (Mulet-Marquis & Fairweather, 2008, p. 5). This trend continued through the first decade of the 21st century, with some 2,000 fewer dairy herds by the end of the decade (LIC & DairyNZ, 2013). However, despite the decline in dairy herds and dairy farms, total hectares farmed increased substantially. From the 1999/2000 dairy season to the 2012/13 one, there was an increase of 400,000 hectares, from 1.3 million hectares (LIC & DairyNZ, 2013, p. 7). Correspondingly, there was an increase in the number of cows per hectare, from 2.07 in the early 1980s, to 2.53 at the turn of the century, to 2.85 cows per hectare by the 2012/13 season, as herd sizes increased greatly, from an average herd size of 236 cows to 402 cows per herd (LIC & DairyNZ, 2013).

¹ Exact numbers are uncertain. Mulet-Marquis and Fairweather (2008) suggest a decline from around 32,000 down to 25,000 dairy farms between 1981 and 1997, but later only report 16,000 dairy herds in 1981. LIC and DairyNZ (2013) reports 16,000 dairy herds in 1981.

Much of the increase occurred in non-traditional dairy areas, especially in the South Island and most strikingly in Canterbury. In McChesney's (1979) study until the early 1990s, there were around 20,000 hectares of dairy farms in the Canterbury region (Pangborn, 2012, p. 18). By the time of Wells' study, that number was closer to 100,000 hectares, and by the end of the decade there were nearly 200,000 hectares of dairy farms in Canterbury (Pangborn & Woodford, 2011, p. 83). While Canterbury has had the most dramatic increase, large increases occurred across the South Island, including Otago (PCE, 2004, p. 36). Growth in the South Island was such that it went from producing less than 10% of the national total in the mid-1980s, to around 40% by the 2010s (Pangborn, 2012).

2.3.3 Fertilisers

The increase in land area and herd size resulted in an increase in production, but this did not occur in isolation. Wells identified nitrogen fertilisers as a major driver of the increased energy intensity of farms, and this was observed nationally as well, with dramatic increases in nitrogenous and non-nitrogenous fertiliser application from the 1990s (MacLeod & Moller, 2006, p. 208). In the dairy industry, the increase in nitrogenous fertilisers was similarly rapid and massive, albeit from a very low baseline (Clark, Caradus, Monaghan, Sharp, & Thorrold, 2007). A study of Waikato region dairy farms found that there were slight declines in non-nitrogenous fertiliser applications, but very large increases in nitrogenous fertiliser applications. Judge and Ledgard (2009) found average usage of nitrogen increased by 220% between 1997/8 and 2007/8. Nitrogen usage increased most significantly on lower-than-average production farms, but in all categories the increase was over 150%.

2.3.4 Irrigation

Most irrigated land in New Zealand is located in the Canterbury region, where approximately 400,000 hectares are irrigated, although there has been an increase in irrigation in other regions (Pangborn, 2012; PCE, 2004). Around a third of the nation's irrigation was estimated to be for dairy farms in 2001. MacLeod and Moller (2006) estimated a long-term average increase in irrigated agricultural land of 4% per annum. By 2012/3 irrigated land in New Zealand had surpassed 700,000 hectares, and was expected still to have another 300,000 hectares of potential irrigable land (Irrigation NZ, 2015).

2.3.5 Summary

There have been substantial changes in the dairy industry in the time since the Wells survey of 2001). The next section looks at the resurgence in energy studies in the same time frame.

2.4 Energy and Agriculture since 2001

After Wells' study, interest in energy and agriculture was rekindled, with a focus on reducing environmental impacts. In 2004, the Energy Efficiency and Conservation Authority (EECA) commissioned a new review of the total energy inputs and their use on farms of the New Zealand agricultural sector. The report by Wilson, Barrie, Sims, Jollands, and Holland (2004) considered the total energy inputs of a variety of major farming sectors, including sheep and beef, dairy, arable crops, intensive pig and poultry, indoor intensive crops, and fruit production. Particular focus was given to the dairying sector as it was both the largest sector and also had the highest energy intensity.

For each sector, excluding dairy, data was drawn from the existing literature. For the most part, this relied on the research from the 1970s and 1980s. Aside from dairy, only arable crops and indoor intensive crops had recent data, for instance by Barber (2004), that was used to update earlier data. However, most sectors did not have any recent data, and so the report relied on the earlier data available. Each agricultural sector was described, with key energy inputs identified. A projection on the state of the industry in New Zealand was given, up until the year 2012. Areas where energy efficiency gains might be possible were identified for each sector; however, there was no verification or in-depth analysis of this.

For the dairy sector, the study by Wells (2001) was combined with the Ministry of Agriculture & Fisheries (MAF) Pastoral monitoring models to update electricity use. The second part of the dairy sector study was an overview of the opportunities for energy savings. This included hot water cylinder operations, milk cooling, fertiliser application practices, and pasture conservation (Wilson et al., 2004).

The report found that electricity expenditure was increasing steadily annually from the levels recorded by Wells (2001), and that with the growth in the dairy industry expected to remain strong, total energy inputs required would also increase.

2.4.1 Energy Studies in Agricultural Sectors excluding Dairy

There were also a number of energy analyses conducted on other agricultural sectors in New Zealand following Wells (2001). Two are given here in detail; however, a range of other sectors have been covered, including apples (Frater, 2010) and sheep and beef (Barber & Lucock, 2006).

Wheat

Several studies, begun by Safa (2011) examined the total energy consumption of wheat production in Canterbury, limited to on-farm energy consumption (Safa et al., 2011). Canterbury wheat farms account for 87% of the wheat produced in New Zealand (Safa, 2011, p. 82). Safa drew on more inputs than Wells, for example including the energy input of human labour, while the subject framework required other impacts, such as seed (Safa, 2011). Safa collected data from an independent survey of 40 wheat farmers from the Canterbury region, in 2006/07 (Safa & Samarasinghe, 2011). Safa also included indirect factors, such as the social status and level of formal education of farmers in his survey. Safa hypothesised that the differences in age, practical experience, and formal education - alongside other social and personal factors - would also influence the energy consumption of farmers, with higher educated or experienced farmers having lower energy consumption (Safa, 2011, p. 96).

One of Safa's main challenges was poor reporting of energy consumption from surveyed farmers. For instance, only 37% of farmers surveyed had estimations of their on-farm fuel use (Safa et al., 2011). Furthermore, a "significant number" of those estimations were found to be inaccurate (Safa et al., 2011, p. 5402). Therefore, it was necessary for Safa to make estimations based on the Lincoln University farm budget for fuel use. These inaccuracies were also found for other variables measured by Safa, and as such there was a lower level of accuracy than hoped for, with gaps in knowledge being filled by estimations and assumptions from other work. The lack of accurate data was often due to a lack of awareness or understanding of energy issues, with financial data being the most reliable measure. However, financial data is an imperfect measurement tool for energy, and only direct energy sources are typically measured. Safa also found that farmers tended to be reluctant to open their financial accounts to external scrutiny (Safa, 2011). Farmers' interest in fuel consumption appeared to be related to the price of fuel, with interest in retaining information on fuel consumption on-farm increasing in 2006 and 2007, and decreasing as fuel prices fell in 2008. This changing interest was matched by changes in data integrity and completeness. Irrigation was found to be the

most important farm operation for energy consumption. Non-irrigated, dry-land farms used an average of 3.2 GJ/ha/yr, while irrigated farms used an average of 10.9 GJ/ha/yr (Safa et al., 2011). Irrigation comprised the greatest proportion of energy consumption (71%) for farm operations. In contrast, the greatest single farm operation variable for dry-land farms, tillage, comprised 46% of energy consumption. Tillage formed only 12% of energy consumption on irrigated farms, however, despite both using similar quantities of energy per hectare for tillage. Likewise, all other farm operations were similar in terms of their energy consumption and rates in absolute terms. These distinctions demonstrate the great importance that irrigation plays in energy consumption in agriculture overall.

When Safa looked at total energy consumption, fertiliser use was found to be the largest factor on both irrigated and dry land wheat farms. While irrigation made a significant proportion of difference between the two types of farms, it was found to be the second largest factor on irrigated farms. Fertiliser application comprised 46% of total energy on irrigated farms, and 66% on dry land farms (Safa et al., 2011).

Safa found that the energy ratio of wheat production was very high, giving an Overall Energy Ratio of 0.38 versus Wells' 0.59 for dairy. Safa also expected the irrigated farms' ratio to improve as irrigation efficiency improved.

Crops

In 2004, Barber produced a benchmarking survey of the on-farm energy consumption of various arable crops. This survey covered seven farms, three of which were arable crop farms, three outdoor vegetable farms, and the last an arable and outdoor vegetable farm. The three outdoor vegetable farms were located in the Waikato region, with the remainder in the Canterbury region. Only one farm, an arable farm in Canterbury, was not irrigated (Barber, 2004, p. 20).

Barber identified three critical parameters for describing energy use, based on Smith and McChesney (1979). The parameters are Overall Energy Ratio (total energy outputs divided by total energy inputs), as used by Wells; Energy Intensity (the amount of energy used per hectare); and finally Net Energy Yield (the energy output per hectare minus the input per hectare).

Energy inputs were divided, following the method set out by Brown and Pearson (1977) and Wells (2001), into the three categories of direct, indirect, and capital. An addition to the direct energy category was the inclusion of fuel use by contractors, which was estimated from the type and amount of contracted work (Barber, 2004). The estimation of work by contractors however was based on McChesney et al. (1981), with an update from 1996, and as such may not reflect more recent trends. Nevertheless, the addition of contracted work shows the importance of contractors to agriculture that may otherwise be overlooked. The indirect and capital energy inputs were based on the estimations from Pimentel (1980) and Wells (2001), with some updating based on product withdrawals in the case of Pimentel's (1980)'s agrichemical product market changes.

Energy coefficients for the arable and vegetable crops produced were used from the literature, especially studies from the United States Department of Agriculture. Carbon Dioxide and greenhouse gas emissions, as well as consumer energy values, were calculated from data from the New Zealand Ministry of Economic Development, with the conversions from consumer energy to primary energy that were used from Wells (2001).

The three vegetable farms were analysed by comparing their onion crops, while two of the arable farms used irrigation and were compared separately from the non-irrigating farm. The resulting total energy breakdowns for the irrigated arable farms were 58% direct (46% electricity, 12% diesel), 32% indirect (28% fertiliser, 4% agrochemicals), and 8% capital. In contrast, the non-irrigating arable farm had a negligible percentage of electricity use, resulting in 19% direct energy (almost entirely diesel), 66% indirect (60% fertiliser, 6% agrochemicals), and the remaining 15% capital energy. The onion operations used a more even breakdown of direct and indirect energy, with 41% direct (almost entirely diesel), 49% indirect (25% fertiliser, 24% agrochemicals), and 10% capital energy.

The resulting total energy intensity for the irrigated arable operations was 35 GJ/ha/yr. In contrast, the non-irrigated arable farm had a total energy input of 20.2 GJ/ha/yr. While most of this difference can be explained by the use of irrigation in the first two farms, there was variation in diesel for field operations between the irrigated and non-irrigated farms, with the non-irrigated farm using less diesel. Barber states that the non-irrigated farm substituted irrigation for additional fertiliser and agrochemical inputs in order to achieve the same production as the other farms (Barber, 2004, p. 42).

For the onion operations, total energy intensity was 52.3 GJ/ha/yr. However, Barber acknowledges that there was an unusually wet season, which substantially affected the use of agrochemicals for the onion operations. Normal agrochemical usage should have been a quarter to a fifth of what was recorded. This would result in a 'normal year' total energy intensity of around 45 GJ/ha/yr.

The result of these comparisons, however, is that it is difficult to determine whether the differences are due to the intensification of energy inputs over time, or methodological differences, or variations due to climate, individual farmers, or sample size. This is true for New Zealand farms contemporaneously, as well as compared to historical studies, and additionally for comparisons to overseas studies. Barber acknowledges the poor comparability between the historical New Zealand studies and his work; however, there is not the same acknowledgement of the limitations of this study.

A major limitation for the study was the lack of tracking systems for measuring and recording energy inputs on arable and vegetable farms. This was also expressed by Safa (2011) in his research on wheat farms in Canterbury, and appears to be a common theme across many energy studies. Barber notes that there are optimisations that became apparent as part of the energy analysis that would not have been seen before without measuring the energy inputs. Finally, the differences between energy utilisation, in particular the irrigated and non-irrigated arable farms, have not been explored. The financial impacts of the lower energy non-irrigated farms, where irrigation was substituted for fertiliser, were not measured; however, this offers an opportunity for further investigation.

2.4.2 Revisions of Energy Coefficients

Energy coefficients are factors used to convert inputs of the system initially quantified in time, physical or monetary units (Vigne, Vayssières, Lecomte, & Peyraud, 2012). An energy coefficient expresses in megajoules (MJ) per unit of input the amount of energy consumed to produce and transport that input.

Fertilisers

Fertilisers, and particularly nitrogenous fertilisers, form a key part of the total energy inputs for farms, typically the largest single energy input on farms in New Zealand (Barber, 2004; Safa, 2011; Wells, 2001). However, the only available data on fertilisers, particularly that used

by Wells, was based on much older data, typically the earlier energy analyses of the 1970s and 1980s (Ledgard, Boyes, & Brentrup, 2011).

Ledgard et al. (2011) used a lifecycle analysis approach to update the energy coefficients used in New Zealand. For imported fertilisers, information from a recent European lifecycle analysis, which drew on a decade of data, was used. For New Zealand data, surveys were sent to New Zealand fertiliser manufacturers, representing six fertiliser manufacturing plants. Industry personnel in Germany and New Zealand were consulted to develop the system boundaries and data requirements, while the lifecycle analysis itself was independently reviewed by a German institute.

Despite the age of the previous energy coefficients, there were no significant differences between the energy coefficients used by Wells (2001). In the case of urea, the Middle Eastern source was calculated to be 23.93 MJ/kg, Chinese urea was calculated to be 33.08 MJ/kg, and New Zealand-produced urea was calculated to be 29.47 MJ/kg. This gave an average of 28.9 MJ/kg, which is very similar to the 30 MJ/kg used by Wells (2001).

Very similar results were found for superphosphate, and lime. However, the figure for lime was based on results from a single New Zealand provider, and other sources of lime were not assessed.

Overall, the difference between the previous coefficients and the updated coefficients as a proportion of energy requirements on farms were found by Ledgard et al. (2011) to be minor overall.

Irrigation

Irrigation was identified by Wells (2001) as the other major contributor to total energy inputs in dairying, and across the country irrigated land was increasing at a steady rate (see section 2.3.4). By the early 2000s, there was a lack of recent, reliable data on the energy requirements of irrigation but irrigation was estimated to have 250MW of installed capacity. Energy consumption was estimated at 300-500gigawatt hours (GWh) per year, with annual increases of around 5% per annum (McChesney, McIndoe, & Martin, 2004).

As previously stated, a large proportion of the increase in irrigated land has been driven by dairying, with the potential for irrigated land in New Zealand to double, with around two-thirds of that expected to occur in the Canterbury region (McChesney et al., 2004, p. 9).

The key irrigation variables on energy requirements were described by McChesney et al (2004), with the strongest variables being the depth of well pumping, and the area irrigated (see Table 5).

	Components	Effect on energy
Pump pressure	Depth from which water is being lifted from a well (or other source)	Strong
	Elevation to which water is being pumped	Generally small but can be strong
	Energy absorbed in the drive system of the irrigator (if water-driven)	Generally small
	Pressure at which the water is released from the irrigation outlets	Moderate-strong
Flow rate/ volume of water pumped (flow rate times hours pumped)	Water demand of the crop (crop type, climate, soil characteristics)	Moderate/strong
	Area irrigated	Strong
Efficiency factors (energy and water)	Motor and pump efficiency	Small-moderate
	Losses in the pipe network, reticulation and hydraulic control system	Generally small
	Efficiency of the well and well screen	Generally small
	Efficiency with which water is delivered to the soil by the irrigation device	Moderate
	Efficiency with which the farmer manages the timing and quantity of water applications	Moderate-strong, particularly in high rainfall years

Table 5: Effect of Irrigation Variables on Energy Requirements (McChesney et al., 2004, p.11)

McChesney et al. (2004) estimated that the energy utilisation of irrigation was around 1.5 gigawatt hours(GWh) per megawatt (MW) of installed capacity, with a range between 1 and 2 GWh/MW. Deeper pumped wells could have around a third higher energy utilisation than shallow pumped wells. Energy utilisation would also vary depending on the climatic conditions of the season, and also tended to be higher on dairy farms.

McChesney et al. evaluated different irrigation system types (Table 6). This evaluation found that there is a substantial difference in the energy requirements for applied irrigation between different system types. McChesney et al. used a basic measure of the kilowatt-hours required to apply one millimetre of water to a hectare, assuming a constant water availability at ground level, and then adjusted that measure to include some application inefficiency. This provided the net values (Table 6, column 3).

System Type	Outlet Operating Pressure (m)	KWh/mm.ha applied gross	KWh/mm.ha applied net
Surface drip or drip line/subsurface drip)	7	0.3	0.4
Micro sprinkler (50m lateral@6m)	17.5	0.6	0.7
Centre pivot – fixed and towable	15	0.8	0.9
Hand-move/end tow/side roll	28	1.0	1.2
Rotating boom (small)	15	0.9	1.2
Linear boom (low pressure)	7	1.0	1.3
Linear move (known as lateral move)	15	1.2	1.3
Solid set impact sprinklers	35	1.1	1.5
Rotating boom (e.g. RR250)	20	1.1	1.4
Linear boom (Rotators)	15	1.2	1.4
K Line	30	1.1	1.6
Long lateral	40	1.4	1.6
Linear boom (impact sprinklers)	30	1.5	1.8
Solid set big guns	60	1.9	2.5
Travelling big gun (soft hose)	50	2.0	2.8
Hard hose big gun	60	2.3	3.3

Table 6: Energy requirements of different irrigation types (McChesney et al., 2004, p.23)

This demonstrates the role of particular irrigation systems on energy requirements. This was reflected in a trend towards more efficient irrigation types (e.g. centre pivot systems on dairy farms) in new installations. However, McChesney et al. noted the capital costs of changing systems as a significant barrier to the upgrading of irrigation systems.

Other irrigation system elements explored included well efficiency, which is an area where there is limited research. McChesney et al. noted that there could be savings of 40-80 kilowatt hours per hectare per year, although it was uncertain how much this could be realised without further study.

McChesney et al. conducted an audit of irrigated farms in Canterbury to explore possibilities for energy savings. Overall, energy savings for all farm types averaged 16% of irrigation energy costs, and 19% for the dairy farms audited. However, it was unclear how much of those savings could be economically realised, as well efficiency and technology upgrades are either poorly understood or financially intensive.

McChesney et al. found that there was a good scope for improving energy through improved irrigation management practices, and that newer technologies such as centre pivot irrigators could be more precise in applying water. The best opportunity for improving the energy consumption of irrigation systems is at the system design and installation phase, as well-constructed systems could have significant savings. McChesney et al. noted that energy analysis and the savings from reduced energy costs was often not presented to farmers, who instead tended to only receive information on the capital costs of irrigation systems (McChesney et al., 2004, p. 29).

Overall, McChesney et al. provided valuable information regarding the energy requirement of irrigation systems, including the difference between various systems. This analysis also included key variables for determining irrigation system energy requirements, such as water pump depth. McChesney et al. show that there is scope for energy savings through improved system design and management practices.

2.4.3 Dairy Studies

Milking Shed Efficiency

Sims, Jayamah, Barrie, Hartman, and Berndt (2004) built on the electricity section from the study by Wilson et al. (2004) to look in detail at the potential for electricity savings on dairy farms. Electricity was chosen as it was the main direct energy input on dairy farms. Other inputs, such as fertilisers or supplementary feeds, were not analysed. In addition, the report was scoped to only look at electricity consumption in the milking shed.

The first part of the study was based on results obtained from a survey of 62 farms, roughly equally divided around the country. The survey was comprised of a semi-structured interview with the farmer, and a walk-through observation of the milking shed for each farm, noting machinery and equipment. This data was then used in combination with a computer model to calculate energy flows in the milking shed, and generate results for each of the surveyed farms, the typical farm, and an energy efficient farm. These results were returned to the farmers surveyed.

The data from all farms was then used to identify energy efficient technology options based on farms, which had made successful energy savings, as well as to illustrate where savings could be made (Sims et al., 2004).

The second part of the study involved detailed analysis of three case study milking sheds. The milking sheds were of a modern large rotary style, a medium herringbone, and an older, small herringbone style. Four milking shed subsystems (water heating, milk chilling, milking machinery, and pumping) were measured with energy meters for a week.

Sims et al. (2004) then analysed the results of the energy monitoring to determine which subsystems had the most potential for energy savings. The largest savings could be made by using variable vacuum pumping as opposed to constant vacuum pumping. This change would result in a reduction of approximately 20% of the total electricity used by the milking shed (Sims et al., 2004, p. 44). Other major factors included pre-chilling of milk through heat exchanges (approximately 6% total reduction), insulation of vats (2-3% total reduction), and improving heating efficiency (2-3% total reduction).

The report demonstrated that there are some significant energy savings that can be achieved in the milking shed, however these savings are often not being realised due to a lack of information and awareness of energy issues.

Dairy Case Study – Lincoln University Dairy Farm

Barber (2008) conducted a study on the resource use and production inventory in order to create a lifecycle benchmark for the Lincoln University Dairy Farm (LUDF), based on the 2006/7 season. The LUDF was characterised as a low input – high production dairy farm, located in the central South Island of New Zealand. In addition to creating a lifecycle benchmark for the LUDF, the study would also compare the LUDF to contemporary and historical New Zealand farms. However, in practice, there are not significant differences in the methodologies between Barber's previous work on arable and vegetable crops or other energy studies. Some areas that are different are within the context of lifecycle analyses, such as the selection of biological allocation for determining environmental burdens (Barber, 2008, p. 11). Barber's report had much better OER of 0.55, which is considerably lower than the average Canterbury OER of 0.99 that Wells (2001) found for the 1997/8 season. However, in spite of this, Barber found that the LUDF had a higher energy intensity than the average Canterbury farm from Wells' research. However, the LUDF is not representative of an average Canterbury farm, so while the LUDF may contribute to the intensification of the Canterbury dairy industry; it is not necessarily representative of it.

Dairy Farm Case study – Canterbury Pastoral Model

Latham (2010) produced a dissertation that set out to compare the relationship between energy efficiency and farming systems. It should be noted that Latham used the terms “energy intensity” and “intensification” to refer to energy required per unit of production, which differs from the use of those terms as used by other New Zealand literatures, particularly Wells (2001). Latham sought to use a lifecycle analysis to model and compare a ‘typical Canterbury farm’ with two intensified dairy scenarios in the McKenzie district of New Zealand. The McKenzie district is within the region of Canterbury, but significant dairy farming is relatively new and uncommon even compared to the rest of Canterbury as a region. The McKenzie district was identified as an area for future growth in the dairy industry in Canterbury, as well as one where colder and more alpine climatic conditions would require different farming systems. Latham sought to model a simulated McKenzie district farm both with and without herd housing, where dairy cattle would be kept indoors for most of the year. As this practice is very rare in New Zealand, this modelled farm would represent a much more intensive form of dairy farming in New Zealand.

The Canterbury model was developed using the then Ministry of Agriculture and Fisheries (MAF) Pastoral Modelling Programme. The programme creates a set of model farms that are typical for the industry and the region. Latham (2010) used the MAF 2009 season model for their research. Latham was however unable to find sufficient data to complete the McKenzie district scenarios, as industry-acceptable data was not available and had not yet been conducted. Further, data on herd homes was not available, as herd homes in the McKenzie district were proposed systems rather did not proceed. Efforts to identify a suitable case study were also not successful, and communications with several analysts confirmed that Latham’s intensive scenarios were too novel to have sufficient industry-acceptable data.

Latham used a life-cycle analysis approach, and drew her energy data from Saunders and Barber (2007); Saunders et al. (2006). Saunders and Barber and Saunders et al. in turn used data from Wells (2001). Latham found that the Canterbury model had an energy split of 42% for direct energy, 51% for indirect energy, and 7% for capital energy. The proportion of capital energy was consistent when compared to Wells (2001) for a Canterbury farm, however much lower than Wells’ National Average irrigated farm. The direct and indirect proportions were

also substantially different, with Latham finding a 42/51 split, and Wells finding a 51/42 split. This difference may be due to a shifting proportion due to intensification of farming; however, a higher indirect energy ratio resulting from increased fertiliser and agrichemical use may have been more likely to be expected. Overall, Latham finds that the Canterbury model has a substantial increase in energy consumption against Saunders & Barber's National Average, and that the greenhouse gas emissions per unit of production are nearly twice as high for Latham's Canterbury model as the National Average.

One issue is that Latham misinterpreted Saunders et al. as drawing data from the dairy season of 2001, when in fact Wells (2001) data was based on the 1997-98 and 1998-99 dairy seasons. While Latham compares their findings to the National Average based on Saunders and Barber (2007), the chronological differences are not mentioned. Secondly, Latham does not compare their findings with Wells' Canterbury findings, and instead compares their Canterbury findings with the National Average from Saunders et al. (2006). Unfortunately, Latham did not conduct an analysis using the MAF data available for a national average farm under the same conditions. This may explain some of the differences between Wells and Saunders et al.'s and Latham's models that are due to national trends towards intensification of the dairy industry. Further, Wells found that energy efficiency expressed as OER, had remained largely constant between their 2001 study and the previous research from the 1970s, particularly McChesney (1979). Latham did not measure energy consumed per unit of land area. Wells found that energy intensity by this measure had doubled between the 2001 study and the 1970s research. As such, it is not possible to determine the role improved production may have had on regional and national energy assessment.

2.4.4 International Studies

Internationally, there has been a renewing of interest in energy use analyses in the agricultural sector. A review of the international literature by Vigne, Vayssières, et al. (2012) found 90 published studies in the years 2007-2011, compared with 63 in the years 2002-2006, and 22 between 1997 and 2001 (p.200). Of all the studies found by Vigne, Vayssières, et al. (2012), more than 80% used energy analysis as their methodology. However, very few of these energy analyses studied livestock and mixed farms, highlighting an important research gap internationally. Further, there appears to be a lack of large scale studies, as many of the existing dairy energy analyses consider single case studies, or small numbers of farms.

Austin (2012) conducted an energy analysis on four Australian farms, two each representing small and large scale examples of organic and conventional dairy production. Austin (2012) used a methodology closely based on that of Wells (2001). As with Wells (2001), Austin found that irrigation and fertiliser use were the main drivers of energy consumption on the farms surveyed. While Austin used a megajoules-per-cow measure of energy consumption, this can be normalised to Overall Energy Ratio, the ratio of energy inputs to energy outputs, to give comparisons to other studies. Austin found an average OER of 0.84, with the two organic farms having an average OER of 0.72, and the two conventional farms having an OER of 0.95.

Four studies from the European Union were also found to be highly relevant to this research, Meul, Nevens, Reheul, and Hofman (2007); Thomassen, Dolman, van Calker, and de Boer (2009); Upton et al. (2013); Vigne, Martin, Faverdin, and Peyraud (2012) all conducted energy analyses on conventional dairy farms. The farms surveyed were larger in size and herds than national average, with the exception of those used by Vigne, Martin, et al. (2012), where no comparison is made. However each average farm size and herd size was substantially smaller than those in New Zealand. Farm management was also different, with European farms generally using housed cows and imported feeds much more than would be expected in New Zealand.

For the United States, Heller and Keoleian (2011) investigated the life cycle of milk in a large, vertically-integrated organic dairy operation. This study included off-farm activities, an advantage of having a single, vertically-integrated entity. The on-farm boundaries included each of the six farms that supplied the company. The on-farm processes were found to comprise around a third of the total energy required for the entire life cycle of milk.

International comparisons were also made by Wells (2001), drawing on international literature, and Saunders et al. (2006), using a modelled farm. Table 7 shows the range of Overall Energy Ratios found from international studies on dairy farms. The low number of the farms surveyed in some studies indicate that the results may not be indicative of the wider industry for that nation.

Study	Data Year	Nation	# of Farms	OER
Uhlen et al, in Wells (2001)	1997	Sweden	?	2.4
Pimental, in Wells (2001)	1997	USA	?	2.8
Halberg et al, in Wells (2001)	1998	Denmark	15	0.96
Muel et al	2001	Belgium	69	0.80
Saunders	2006	UK	1 (modelled)	1.26
Vigne et al	2008	France	42	1.53
Heller & Keoleian	2011	USA	6	2.02
Austin	2012	Australia	2	0.95
Upton et al	2013	Ireland	22	0.84
Thomassen et al	2013	Netherlands	119	0.87

Table 7: Comparison of international Overall Energy Ratios

However, the similarity in Overall Energy Ratios amongst the European studies suggests that an acceptable average may be taken. Including the outlying Swedish figures, the European average OER is 1.24. Excluding the Swedish data, the average is 1.04. The conventional Australian farms also have an average of 0.95, while the United States farms have an average OER of 2.4.

2.5 Research Gap & Question

The literature review has shown that despite a renewed interest in energy analysis in New Zealand, there has not been a comprehensive national study on the dairy industry since Wells (2001).

Secondly, there have been substantial changes within the dairy industry, particularly in the areas of irrigation and fertiliser use. There has been a large change in land use, particularly in Canterbury, which has previously been identified as the most energy intensive dairy farming region. An increased use of supplementary feeds has been represented by the use of supplementary feed use as a categoriser of dairy farms since 2005.

There is a body of work, dating back to the 1970s, which allows for comparisons covering the evolution of the energy requirements of dairy farming across the decades.

The energy coefficients provided by Ledgard et al. (2011); McChesney et al. (2004) allow for the most accurate data to be calculated, and the experiences of several other energy analyses demonstrate comparable methodologies with which to build on.

There is therefore a clear research gap in the energy analysis field for large, nationwide studies for agricultural sectors, and in particular for dairy as a high energy intensity sector. Such a survey will allow for New Zealand's performance to be measured across time in a way that will uncover the key drivers of energy change. The regions that require the highest and lowest energy inputs can then be identified, and the

Additionally, New Zealand's competitive advantage against major international competitors will be able to be assessed, and further, it will be possible to analyse the growth in intensity in the dairy industry across multiple variables.

2.5.1 Research Question

This research will therefore seek to answer these questions:

- How does energy intensity and Overall Energy Ratio in the New Zealand dairy industry evolve over time?
- What factors have driven this evolution?
- What do these changes reveal about implications for production?
- How does New Zealand compare against key international competitors?

Chapter 3

Methods

This research builds on the existing historical baseline data on total energy inputs, to track this change in the energy consumption of the New Zealand dairy sector. Contemporary data has been collected from the database DairyBase and a pilot study was conducted using the Lincoln University Dairy Farm (LUDF) in order to test and calibrate the methods for analysing the DairyBase data. The development of an energy analysis that is based on existing industry financial performance benchmarks to track energy intensity and OER alongside other factors such as yield, land use, and herd size should play a valuable role as a tool for farmers and policy makers to view overall sustainability of dairy farming across time and location, as well as across various farming systems.

3.1 Scope and Boundaries

This research has not sought to redefine the existing energy factors (see Table 10), and thus assumes that there has been no significant change in those factors recently. This is partly based on the commonalities between factors used in other studies, and on the use of very similar identities used regularly by government.

The scope of the research is to look at the New Zealand dairy industry both nationally and at a regional level. Sub-regional data has been collected, and this will be aggregated to DairyNZ's existing regional models. The regional breakdown is desirable because it is expected that there will continue to be significant regional disparities in total energy inputs and in OER.

3.1.1 Defining Farm Boundaries

In general, the definition of the farm boundary is “on-farm to farm gate”. The scope of this research is defined as “on-farm to farm gate”. The farm gate refers to the point where farm products leave the farm property. Setting the boundary at the farm gate is consistent across the previous energy studies conducted in New Zealand as well as internationally. This ensures maximum degree of research compatibility with global energy analyses as well as with the historical records available to New Zealand.

The definition of “on-farm” includes the energy that is directly consumed on farm, as well as the consumption of products that have been produced off-farm, such as fertilisers and supplementary feeds. The energy required for capital inputs, such as machinery, is also included in this analysis. Solar energy, in the form of sunshine, and human and animal labour are not included.

There is already an established methodology for these activities in the energy sense, as established by Barber (2004); Chudleigh and Greer (1984); Dawson (1978); Miller and Vickers (1982); Safa (2011); Wells (2001) in New Zealand, and by Pimentel (1980) and others internationally. There is also an established methodology to account for energy applications that occurred off-farm before the products were applied on the farm, which can be thought of as “one step off farm”, that is, the energy required to produce fertilisers is included, but not that of the machinery used in fertiliser production.

3.1.2 The Functional Units

There are three functional units that were used in this research. These functional units allow for comparisons across farms geographically, temporally, and across research.

The first functional unit is kilograms of milk solids produced.

The second functional unit is hectares of effective milking area.

The third functional unit used is the joule. In practice, the joule is expressed in megajoules (MJ) or gigajoules (GJ).

All data is for the dairy season of 2012-13.

In the case of the first functional unit, kilograms of milk solids produced are often the basis for income for dairy farms, and the same functional unit has been used in the studies for comparison.

The second functional unit uses the definition of “effective milking area”. The “effective milking area” is defined as the total farm area less any land that cannot be grazed or is unproductive. While there is a range of different approaches to the use of imported supplementary feeds or grazing cows off the farm, the effective milking area definition remains the same for each.

Firstly, the Overall Energy Ratio (OER) is the ratio of total energy inputs to the energy value of milk outputs. The OER allows the relative production efficiency (although it expresses the inverse, a lower OER is more efficient) to be compared across multiple dimensions, such as region or production system. An alternative way of presenting this is by displaying the megajoules per kilogram of milk solids, for comparison with the energy intensity

Secondly, energy intensity is the number of units of energy applied per hectare of effective milking area. Energy intensity is not directly tied to production, and so provides a total per-hectare view of energy inputs.

3.1.3 Data Requirements

'Energy' as understood in this research refers to total primary energy inputs. This follows the model of Barber (2008); Latham (2010); McChesney (1979); Wells (2001), as a study on the total energy of dairy farms, so that there is comparability between this study and those previous. Further, there has been a gap in research on total energy inputs since Wells' (2001) report. In order to distinguish between total energy and direct energy, the following breakdown of energy categorisations was used:

Direct Energy	Direct energy refers to the direct application of energy forms to the required process. As described in the literature review, primary energy most commonly refers to fuel consumption and electricity usage.
Indirect Energy	Indirect energy refers to the embodied energy in products which are applied to processes. Indirect energy will refer to the use of supplementary feeds, irrigation (where not previously covered by direct energy), and fertiliser and agrichemical applications.
Capital Energy	Capital energy refers to the embodied energy within plant, buildings, and vehicles.

Table 8: Categorisations of energy

Together, the combination of these categories of energy forms provided the total energy input. Some clarifications and calculations are necessary around these particular definitions. Both direct and indirect energy will be calculated on an annual basis, while capital energy inputs are discounted across their expected lifespan.

3.2 Data collection

Data was collected from the farming database DairyBase, maintained by Dairy NZ, for the dairy season 2012-13. DairyBase is a comprehensive New Zealand database managed by the main industry-good organisation representing the dairy industry, DairyNZ. While farmers are not required to join the database, it nevertheless provides a high level of coverage of the dairy industry. The key advantage of DairyBase over researcher-led surveys is that DairyBase collects annual data from hundreds of farmers, with the numbers increasing every year. Thus, the common problems with surveys, such as low response rates can be avoided. The major issue with utilizing the DairyBase data is, however, that the focus of DairyBase is to provide financial benchmarking, and as such does not provide detailed data for energy consumption. In order to ensure that the data provided by DairyBase can be adapted for energy analysis, a pilot study was conducted using data provided by the Lincoln University Dairy Farm (LUDF), a University-owned but commercially-run best-practice farm. Previous literature on the LUDF provided a background analysis that was used to compare the method of using financial reports to estimate energy consumption. LUDF became the testing ground for the conversion of financial reports to energy data, and was used to initially test and validate the method.

3.2.1 LUDF

The Lincoln University Dairy farm is run by the South Island Dairy Development Corporation. The LUDF has the objective to “develop and demonstrate world-best practice pasture based dairy farming system” and to “consider the farm’s full environmental footprint, land requirement, resource use and efficiency in system decision making and reporting” (SIDDC, 2015). In addition, it monitors and records more data as contributions towards other research purposes than other commercial farms, and as such it has been able to provide more accurate data than that collected by DairyBase. Data was provided in the pre-existing form of financial reports, covering the information provided annually to DairyBase, and also a more detailed breakdown of specific quantities (for instance, litres of fuel used on farm, alongside the dollar expenditure on fuels).

The validation study was developed using data provided by LUDF. This allowed the testing of the energy coefficients with a more complete data set, and also with a comparison with Barber (2008). This validation study used the energy coefficients identified in Section 3.2.3, and also was used to determine the calculations for financial data. As the LUDF data often contained

actual usage, for instance fuel, alongside financial expenditure, it was possible to check that the assumptions made in calculations of energy coefficients and in conversions from dollars to megajoules were consistent. However, the LUDF had adopted a policy of closely managing its environmental impact at a constant level. It was discovered that this policy was successful, with the results being very similar to the report conducted by Barber (2008), despite some differences in data clarity. While this was a positive test for the method – and for LUDF’s environmental management policy– it did not return results that would be sufficiently distinguishable from existing literature.

3.2.2 DairyBase

From DairyBase, a range of data was requested (see Table 9). DairyBase collects data from several sources, with annual surveys sent out for general farm data and physical farm data while financial data is taken from farm accounts (D. Silva-Villacorta, pers. comm., February 16, 2015). DairyBase collects data from the previously completed dairy season, thus the most recent completed season for which data is available is 2012/13. Furthermore, it is necessary to collect farm data in order to analyse changes to energy ratios. Key performance indicators of New Zealand dairy farming have been well established, for instance in Hedley et al. (2006) and a wide range of industry sources, have also been adapted as key indicators for energy analysis.

DairyBase’s data collection methods, including the methodology for determining the representational farms, and the survey methods used to collect the financial data, were withheld due to commercial sensitivity. The data received from DairyBase comprised 134 representational farms. Each representational farm was a mean farm for each of the 54 districts, with additional farms covering production system, and irrigated versus non-irrigated categories. For categorical data, the supplied representational farms represented the majority for that district. Thus, for example, if the majority of Production System 3 farms in a region used irrigation, then that representational farm would use irrigation. However, the number of farms used by DairyBase to build each representational farm was not given. Further, an error in the data request to DairyBase led to the agglomeration of production system farms into ‘Low’ (Systems 1&2), “Medium” (System 3), and High (Systems 4&5). There was a delay of three months between the initial request for data and the release of data, and a further four months between the follow-up request for data and the second release of that data which

constricted the data analysis period available. The ability to choose alternative data was restricted by DairyBase's commercial sensitivity requirements.

Key Parameters

Owner-Operator farms were selected because of the completeness of data available in DairyBase. Conversations with farmers and other sources (M. Pangborn, pers. comm. October 7, 2014) revealed that farms with contractors may split some key aspects (for instance, payment of electricity bills) between the farm owner and the share-milker or contractor, with each submitting separate data submissions to DairyBase. While this is especially important when looking at individual farms, it is unclear at what level this may affect aggregation of farms. A solution therefore is to select farms based on their expected completeness of data. Owner-operator farms are still the predominant business model for New Zealand dairy farms (LIC & DairyNZ, 2013, p. 16).

A further parameter was the selection of aggregated data based on territorial authority (District and City Councils). DairyBase anonymised the individual farms by creating representative farms under the other parameters for each territorial authority. A breakdown of the regional distribution of the farms is given in Table 11.

The final key parameter was the inclusion of all production system types (see Section 2.3.1). These were compiled by DairyBase into three categories, with Systems 1 and 2 compiled into a 'Low' production system classification, System 3 farms designated 'Medium', and Systems 4 and 5 designated 'High'.

An additional parameter to be collected is irrigation. Irrigation is expected to play an important role in determining total energy use as well as influencing the proportions of energy sources as demonstrated in Wells' (2001) research. Irrigated and non-irrigated farms were requested from DairyBase for the same parameters. Irrigated and non-irrigated farms would then be returned across a national sample.

From DairyBase, the full list of data requested was as follows:

Variable	Energy Classification
Production System (1-5)	-
Business Type (Owner-Operator)	-
Region	-

District	-
Percentage Milking Area Irrigated	-
Milking Interval (Once per Day/ Twice per Day)	-
Organic/Conventional Farm	-
Peak Cows Milked	-
Effective Dairying Area (hectares)	-
Financial Year – Milk solids kg	-
Production Year – Milk solids kg	-
Inputs	
Phosphate applied for year (kg/ha/year)	Indirect
Potassium applied for year (kg/ha/year)	Indirect
Sulphate applied for year (kg/ha/year)	Indirect
Magnesium applied for year (kg/ha/year)	Indirect
Lime applied for year (kg/ha/year)	Indirect
Area Irrigated (ha)	-
Percentage effective area irrigated	-
Total water applied annually (litres)	-
Expenditure	
Animal Health	Indirect
Farm Dairy	Direct
Electricity	Direct
Feed: Net Made, Purchased, Cropped	Indirect
Calf Feed	Indirect
Total Supplement Expenses	Indirect
Fertiliser	Indirect
Nitrogen	Indirect
Irrigation	Direct
Re-grassing	Indirect
Weed & Pest	Indirect
Vehicles	Capital
Fuel	Direct
Repair & Maintenance – Land & Buildings	Capital
Repair & Maintenance – Plant and Equipment	Capital

Table 9: Key Farm Descriptors requested from DairyBase

Table 9 shows the categorical data that was requested from DairyBase. Section 3.3 describes the effects of DairyBase's development of representational farms on these descriptors.

The data provides actual values of applied fertilisers rather than a financial expenditure. However, not all farms reported actual values of applied fertilisers, and the coefficients for calculating the indirect energy from fertiliser were modified to ensure that farms that reported actual values of applied fertiliser would have these values calculated. For those farms that did not have actual values, a separate coefficient was developed. A further coefficient formula was used on farms that itemised nitrogen separately from other fertilisers, thus there were several different coefficient formulas used depending on level of detail that farms provided (see 3.2.3).

3.2.3 Energy Coefficients

Table 10 lists the resources and their corresponding energy factors. This has been compiled from several sources from the literature, with preference given to the most recent New Zealand sources. More recent research has not significantly altered the energy factors; the numbers for more often calculated energy factors, such as fuels, are consistent with those used by the Ministry for Primary Industries in its annual energy reporting.

Financial Coefficients

In order to convert financial data into energy data, a series of financial coefficients was also used. These were derived from the Financial Budget Manual 2012-13, the MAF Pastoral Dairy Model 2012-13, and from the pilot study conducted on data from LUDF. The financial coefficients were used to determine the number of units. The energy coefficients in Table 10 were then used to convert the units into an energy figure in megajoules.

For irrigation, there was a wide variation in the costs of irrigation. This is due to geographic and system variation, with wide variation between different irrigation systems (see Table 6), and with pumping distance and pressure having a strong impact on energy use (McChesney et al., 2004, p. 11). It is not possible to undertake an energy analysis on each irrigation system used, and so the following assumptions were made. As most irrigation systems use electricity, with a minority of systems using diesel, it was assumed that the representational farms would use electric irrigation systems (McChesney et al., 2004, p. 13). A value of 2.86 kWh/\$ spent on irrigation totally was assumed, following Barber (2008). It is expected that the expenditure

differences between regions and individual representational farms was sufficient to account for the variability in irrigation costs; however, this is further discussed in section 5.3.1.

Resource	Unit	Primary Energy Factor (MJ/unit)
Direct Energy		
Diesel	Litres	45 ²
Petrol	Litres	42 ²
Oil & Lubricants	Litres	47.4 ³
Electricity	kW	8 ²
Irrigation	\$	10.2 ⁵
Indirect Energy		
<i>Fertiliser Components</i>		
Nitrogen (N)	kg	65 ³
Phosphate (P)	kg	15 ⁴
Potassium (K)	kg	10 ⁴
Sulphur (S)	kg	5 ⁴
Magnesium (Mg)	kg	5 ⁴
Lime	kg	0.9 ⁴
Agrichemicals (animal health, weed & pest)	kg active ingredient	105 ⁵
<i>Supplementary Feeds</i>		
Grains	t DM	2700 ⁵
Silage	t DM	1500 ⁴
Hay	t DM	1500 ⁴
Grazing Off	Stock Unit per year	380 ⁵
<i>Other</i>		
Regrassing	per hectare	3915 ⁶
Capital Energy		
Vehicles	per \$1000	25 ⁴
Land & Buildings	per \$1000	37.5 ⁵
Plant and Equipment	per \$1000	25 ⁵

Table 10: List of energy factors and conversions used

For supplementary feeds, the energy coefficients used represent the total energy content, including estimated transport.

² MED (2012)

³ Ledgard et al. (2011)

⁴ Wells (2001)

⁵ Barber (2008)

⁶ Safa (2011)

3.3 Data Summary

DairyBase provided a representative sample of farms that maintained commercial sensitivity. DairyBase extracted the data requested and provided “representational farms”, which were averages of an unspecified number of farms, averaged by district and production factor using the software R (D. Silva-Villacorta, pers. comm., February 16, 2015). For the categorical farm indicators, DairyBase provided representational farms based on the majority of farms for that district. This excluded organic farms and once-a-day milking farms from the sample.

There was only one distinct outlier in farm and herd size, a very large farm in the Otago-Southland region. This farm is included as it is assumed to represent both the extreme of the current New Zealand dairy industry, and also to represent the trend towards significantly larger South Island farms over the more traditional small North Island farms.

3.3.1 Data Cleanup

Despite the fact that DairyBase validated the data, there was a handful of cases where data was returned with highly unusual results. It was found that a small number of representational farms had incorrect values for rates of lime applied per hectare. It was discovered that this value had been entered on the farm with the incorrect unit, and after confirmation with DairyBase these figures were adjusted accordingly.

There were a number of missing data. These ranged from seven farms which did not report a fuel expenditure, to nearly half of the farms which did not separately itemise nitrogen expenditure. The literature and the Ministry of Primary Industries’ Pastoral Models were used to reconstruct the missing data in the case of the latter, with the regional average for each of the farm’s regions taken, and scaled per hectare for the seven farms without fuel expenditure reported. For the farms that did not itemise nitrogen, it was assumed that those farms would likewise follow the Pastoral Model for their region, and that the Fertiliser expenditure would include a proportionate share of nitrogen expenditure. For these farms, the Fertiliser expenditure was calculated to include a proportionate share of nitrogen, while the calculation for those farms that did itemise nitrogen used a different calculation of coefficients.

Method for adjusting for fertilisers

For fertilisers, all representational farms reported fertiliser expenditure. Around half of the farms additionally separately reported nitrogen expenditure. Around a third of farms reported

applied quantities of non-nitrogenous fertilisers. In Excel, a series of IF and AND formulae was used.

For farms that reported applied non-nitrogenous fertilisers and nitrogen expenditure, the coefficients for each were used, and the fertiliser expenditure ignored.

For farms that did not report applied fertiliser quantities, but *did* report separate nitrogen, a regional average application rate of non-nitrogenous fertilisers was drawn from the Pastoral Model for that region, and the coefficients were applied accordingly to the fertiliser expenditure data. The nitrogen coefficients were given from the nitrogen data.

For farms that did not separately report nitrogen or applied fertiliser quantities, a regional average application rate of nitrogen and non-nitrogenous fertilisers was drawn from the Pastoral model for that region, and then the coefficients were applied accordingly.

Capital Data

As the DairyBase data did not record existing capital, this could not be calculated. The DairyBase data only provided data for on-going capital expenditure: plant and equipment, and land and buildings.

Further, it is not possible to determine the exact breakdown of the types of capital purchased. Despite literature on energy coefficients for particular forms of capital expenditure, there was no way to ascertain which types of machinery, for example, had been purchased. Thus only very general coefficients, of 25 MJ/\$1000 for vehicles, plant, and equipment, and 37.5 MJ/\$1000 for land and buildings, were able to be developed, based on the coefficients used in Barber (2008).

Chapter 4

Results

4.1 Geographical And Production Factors

4.1.1 Geographical distribution of surveyed farms

The data received from DairyBase comprised 134 representational farms. Each representational farm was in fact a mean farm for the each of the 54 districts returned, with additional farms covering production system and irrigated versus non-irrigated categories. For categorical data, the supplied representational farms represented the majority for that district. Thus, for example, if the majority of Production System 3 farms in a region used irrigation, then that representational farm would use irrigation. However, the exact number of farms used by DairyBase to build each representational farm was not given.

Region	Number of Farms in Sample	Proportion of Farms in DairyBase Sample	Distribution of Dairy Farms Nationwide ⁷	Difference between Nationwide and DairyBase Sample
Northland	12	8.95%	11.9%	2.95
Waikato	30	22.39%	30.6%	8.21
Bay of Plenty	13	9.70%	9.1%	-0.6
Taranaki	9	6.72%	14.6%	7.88
Lower North Island	21	15.67%	9.2%	-6.47
West-Coast Tasman	11	8.21%	5.1%	-3.11
Marlborough-Canterbury	20	14.93%	8.8%	-6.13
Otago-Southland	18	13.42%	11.1%	-2.32

Table 11: Regional Distribution of Farms

For functional purposes, farms were analysed primarily by region, as the number of farms in each district and each category varied. The regions supplied by DairyBase did not exactly match the regions that the DairyNZ Statistics report uses, therefore the regions used were estimated by merging DairyNZ regions to match those supplied by DairyBase. There does not seem to be an agreed-upon system for geographical breakdowns. DairyBase provided eight

⁷ LIC and DairyNZ (2013)

regions, while in the New Zealand Dairy Statistics 2012-13, there are 17 DairyNZ regions reported, and six LIC regions. As such, there may be some slight differences between the regions used and the DairyNZ regions as some districts may be counted by DairyNZ in a different region to those supplied by DairyBase.

As shown in Table 11, there are differences in the geographical distribution of the representational farms and DairyNZ's statistical reports. The sample provided by DairyBase over-represented the proportion of farms for the South Island, and under-represented the proportion of farms for New Zealand's traditional dairying areas of Waikato and Taranaki. This may introduce some bias into the energy data, as the South Island regions are on average larger than the farms from the traditional dairying areas, as can be seen in Table 12.

4.1.2 Average Production Indicators for Representational Farms

Region	Cows Milked	Farm Size (ha)	Stocking Rate (cows/ha)	Milk Solids Produced (kg MS)	OER	Energy Intensity (GJ/ha/yr)
DairyNZ National Average	402	141	2.85	139,410	-	-
Sample National Average	526	184.24	2.86	201,490	0.82	33.12
Northland	453	187.33	2.42	147,910	0.94	29.25
Waikato	434	162.58	2.76	148,799	0.79	28.69
Bay of Plenty	384	130.61	2.93	136,814	0.81	31.87
Taranaki	333	115.73	2.88	126,955	0.79	31.94
Lower North Island	488	182.63	2.79	195,044	0.64	25.70
West Coast-Tasman	522	215.59	2.48	188,436	0.99	33.72
Marlborough-Canterbury	763	222.29	3.40	319,282	0.97	52.35
Otago-Southland	709	231.67	2.98	293,624	0.66	31.52

Table 12: Key Production and Energy Indicators for Regions

Table 12 shows the key production and energy indicators for the representational farms by region. The key production indicators: cows milked, farm size, stocking rate, and milk solids produced.

The key energy indicators are Overall Energy Ratio (OER) –energy inputs in megajoules divided by the energy content of the milk solids produced; and Energy Intensity – measured in gigajoules per hectare (GJ/ha/yr).

The South Island regions – West Coast-Tasman, Marlborough-Canterbury, and Otago-Southland – all have on average substantially larger farm and herd sizes, and consequently produced more milk solids per farm. The Marlborough-Canterbury and Otago-Southland regions had farms that are more associated with modern trends in the New Zealand dairy industry. Most of the representational region averages exceeded the national average from DairyNZ, in key production indicators. This suggests that the representational farms tended to represent those larger and more productive than the national average regardless of geographical distribution.

While the regions have been averaged for functional purposes, there was also significant diversity between farms within the representational farm sample. Ten farms had effective milking areas below 100ha, however only one representational farm had fewer than 200 cows. At the other end of the scale, there was one particularly large farm, comprising 2,250cows and nearly 550ha. There were five additional farms with more than 1000 cows, however only three farms exceeded 400ha, including the aforementioned. These very large farms represent about 3% of the sample, compared to around 4.6% nationally, while farms with fewer than 200 cows comprise 20.8% of the national herds, but only one of the representational farms collected for this research. As above, this suggests that the representational farms tended to represent larger and more productive farms, although at the highest extreme there are fewer representational farms in the very large herd category than would be expected nationally.

The key energy indicators were not as clearly distributed regionally. The Overall Energy Ratio varied across the regions, and was lowest in traditional dairying regions and higher in modern and growth dairy regions like Marlborough-Canterbury. Likewise, Energy Intensity tended to be higher in those modern dairying regions, and lower in traditional regions.

4.1.3 Relationship between Milk Solids Production and Herd Size

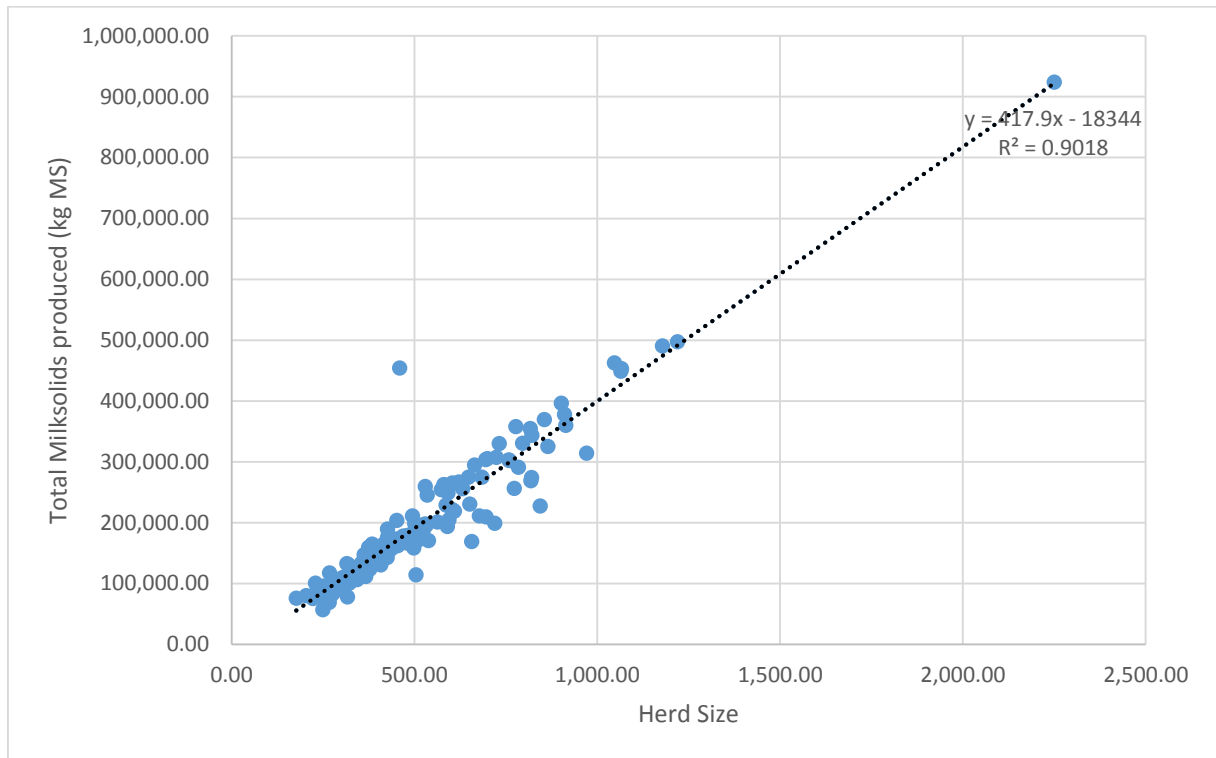


Figure 1: Relationship between milk solid production and herd size

Amongst the representational farms, there is a very strong relationship between milk solid production and herd size. The mean herd size for the representational farms was 536 cows, substantially larger than the DairyNZ national average herd size of 402 cows.

However, the strength of the relationship between herd size and milk solids indicates that regardless of the difference between the national average and the sample average, the results will not be substantially different.

While analysis of the key production factors shows that there is the strongest relationship between herd size and milk solid production, this relationship does not explain the variance in the energy intensity and OER regionally. Therefore, there may be additional factors influencing energy intensity and OER, which are explored in the following sections.

4.2 Energy Indicators

The relationship between total energy inputs and farm size, and the relationship between total energy inputs and milk solid production, were analysed. Total energy inputs were varied, with farms ranging from 1,000 gigajoules (GJ) per annum to a high of over 30,000 gigajoules per annum. This considerable variation is analysed in further detail below. The average total energy input for the sample was 6,250 GJ/yr while average energy output – the energy value of the milk solids produced – was 7,656 GJ/yr.

This gives an Overall Energy Ratio (OER) of 0.82. The lowest OER recorded was 0.25, while an additional fourteen representational farms had OERs of less than 0.5. The highest OER was 2.91, with seven further farms recording OERs above 1.50. Additional to those eight farms, another fifteen farms were calculated to have OERs above 1.0. In total, 17% of the representational farms were calculated to have net energy losses, that is, they required more energy inputs than was output through milk solid production.

4.2.1 Relationship between Total Energy Inputs and herd size

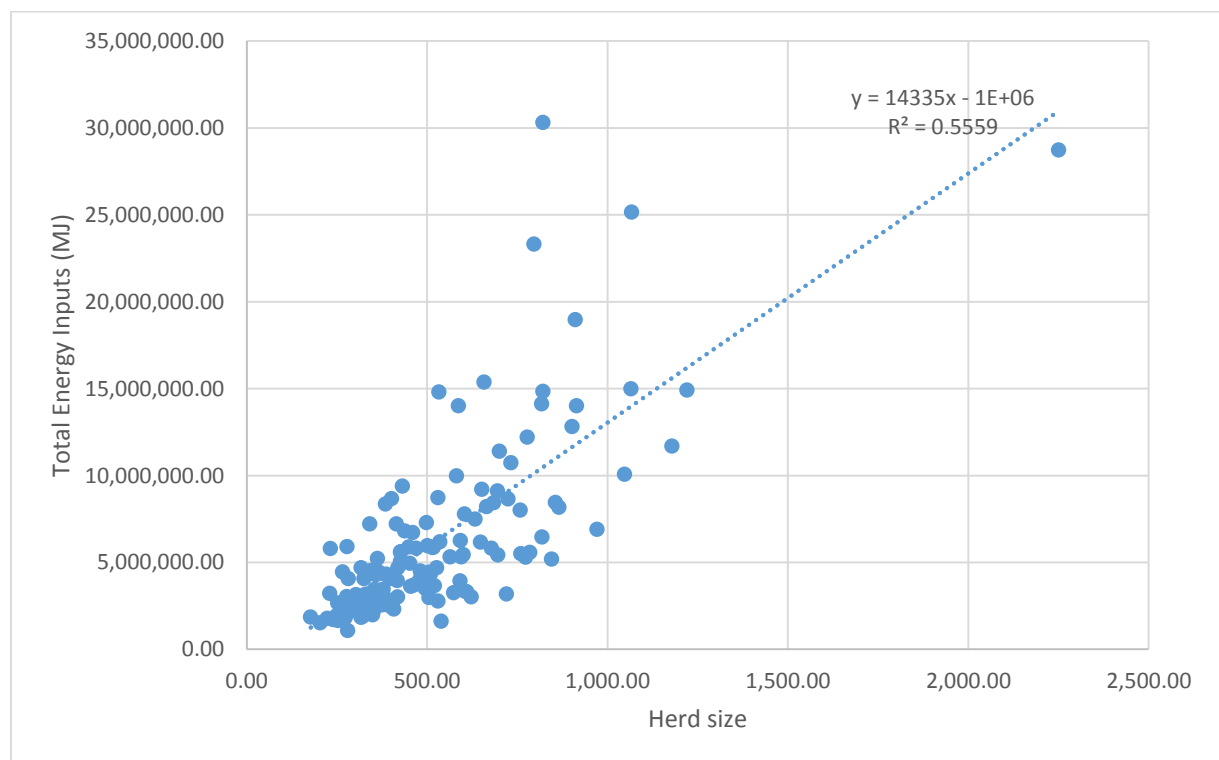


Figure 2: Relationship between Total Energy Inputs and herd size

There is a moderate relationship between herd size and total energy inputs, although a much weaker one than that shown in Figure 1. While there is a strong cluster for the representational farms with fewer than 500 cows, there is a much weaker relationship for

those farms with more than 500 cows. The 2,250 cow farm has a small impact on the overall relationship. When the 2,250 cow farm is removed, the subsequent R^2 value is 0.49, with a similarly slight reduction in slope.

The diversity seen in total energy inputs however cannot be explained in a linear fashion, as additional factors may apply to those cases, such as irrigation explored in Section 4.3, and in regional analyses.

4.2.2 Relationship between Total Energy Inputs and Effective Milking Area

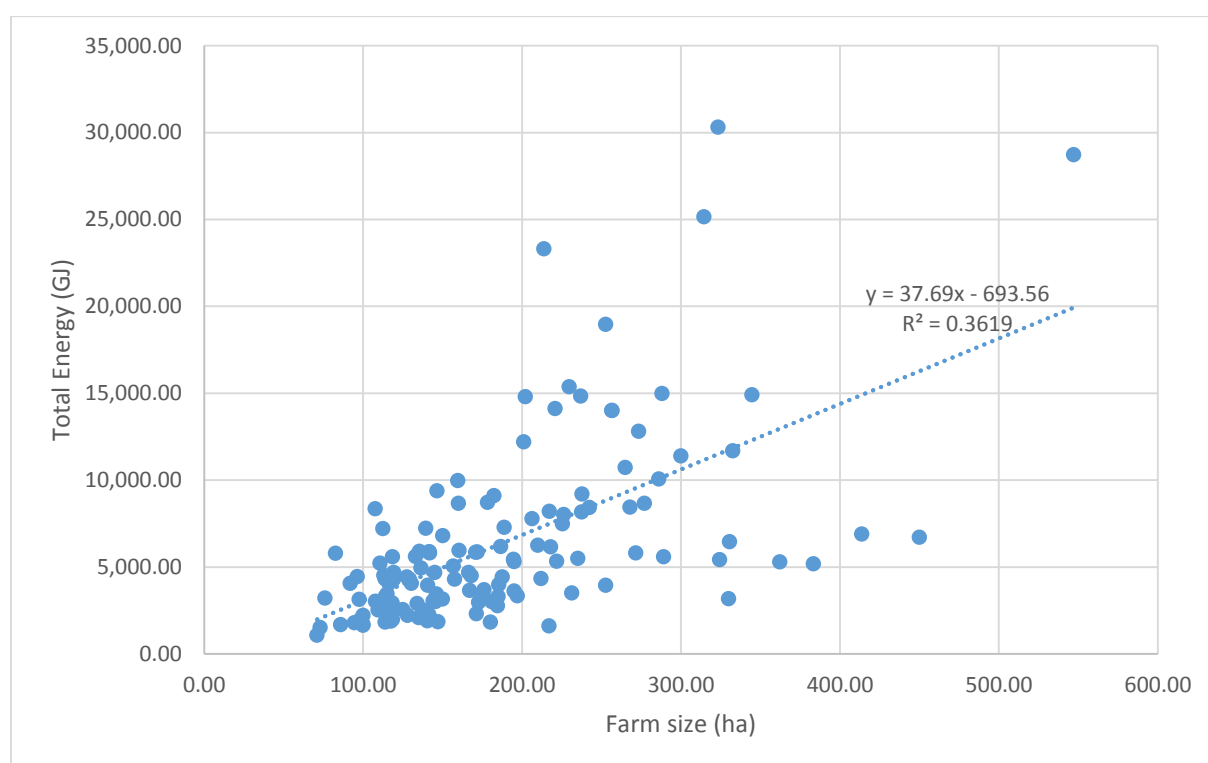


Figure 3: Relationship between Total Energy Inputs and farm size

Total energy inputs increase moderately as farm size increases, and there is a moderate relationship between the two variables. The relationship is much stronger with the smaller farms, but considerably less strong for farms above 200 ha and especially beyond 300 ha. This suggests that there are additional factors that influence total energy inputs particularly for those farms.

There is also a range of farms that have similar total energy inputs across a range of farm sizes, particularly those that cluster around the 5,000 gigajoule line. There is a slight increase in total energy inputs as farm sizes increase even for those farms in that 5,000 gigajoule input cluster. These farms include some of the largest representational farms from the sample; however,

their total energy inputs are similar to those of much smaller farms. On the other hand, there is a slightly-less defined cluster of farms, mostly in the 200-300 ha range, with significantly higher total energy inputs.

The variation between these two clusters, which fall on either side of the regression line, can only be explained by investigating what are the particular features of the farms, and how energy inputs vary between these groups of farms.

4.2.3 Relationship between Total Energy Inputs and Production

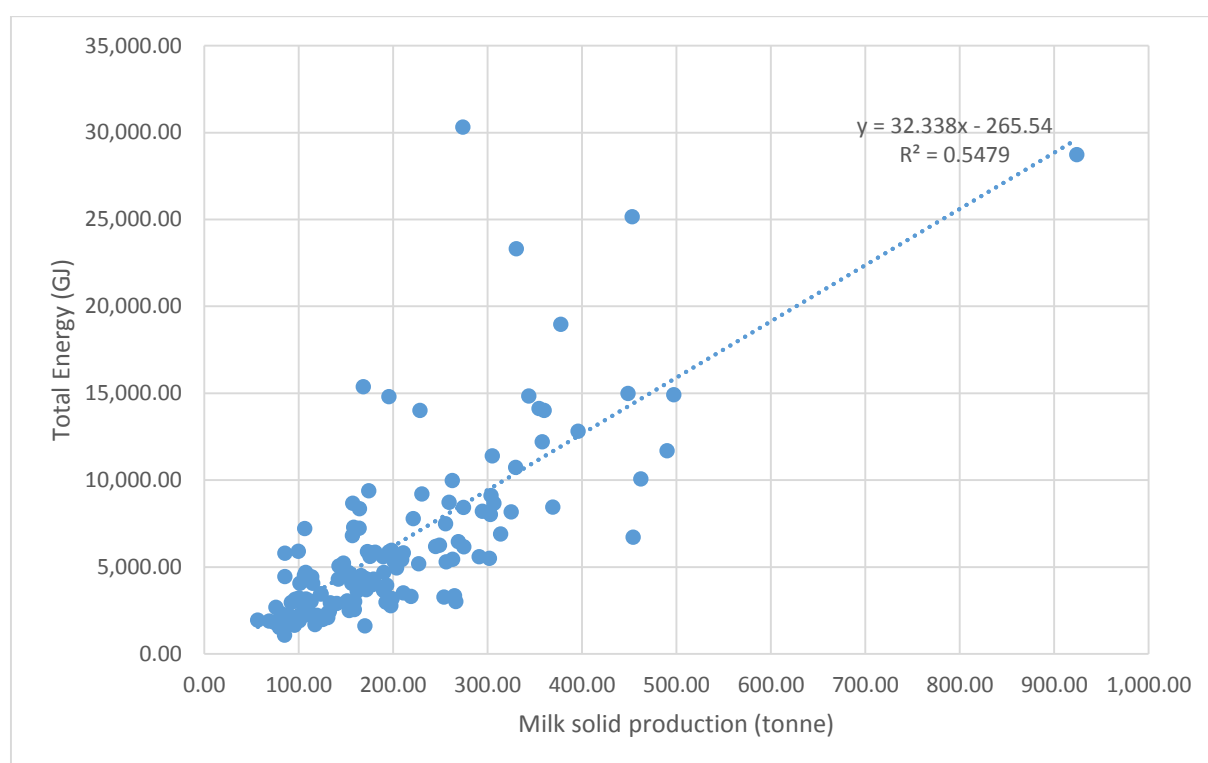


Figure 4: Relationship between Total Energy Inputs and Production

There is a moderately-strong relationship between total energy inputs and milk solids production. Unlike the more even spread of farms as seen in Figure 3, there is only a loose cluster of farms above the regression line where total energy inputs increase substantially. As with the other analyses, most farms are clustered in the low-input, low-output sectors, which reflects the traditional input-production gearing of the New Zealand dairy industry. These farms had total energy inputs between 1,000 GJ/yr and 10,000 GJ/yr, with total milk solid production below 400 tonnes.

Those farms with substantially higher total energy inputs cannot be explained by this analysis however, especially those above 10,000 GJ/yr of total energy inputs. These farms see above

the average of total energy inputs with no, or hardly any, distinct increase in milk solid production.

Finally, Figure 5 shows the relationship between total energy inputs and stocking rate. The farms are scattered in much the same way, as there is variation between farms' stocking rate and other key production indicators. The same low-input, low-output cluster can be seen in the 2.0 to 3.5 cow per hectare range below the line of regression.

These farms consistently demonstrate the low-input, low-output model that has been typical of the New Zealand dairy industry.

4.2.4 Relationship between Total Energy Inputs and Stocking Rate

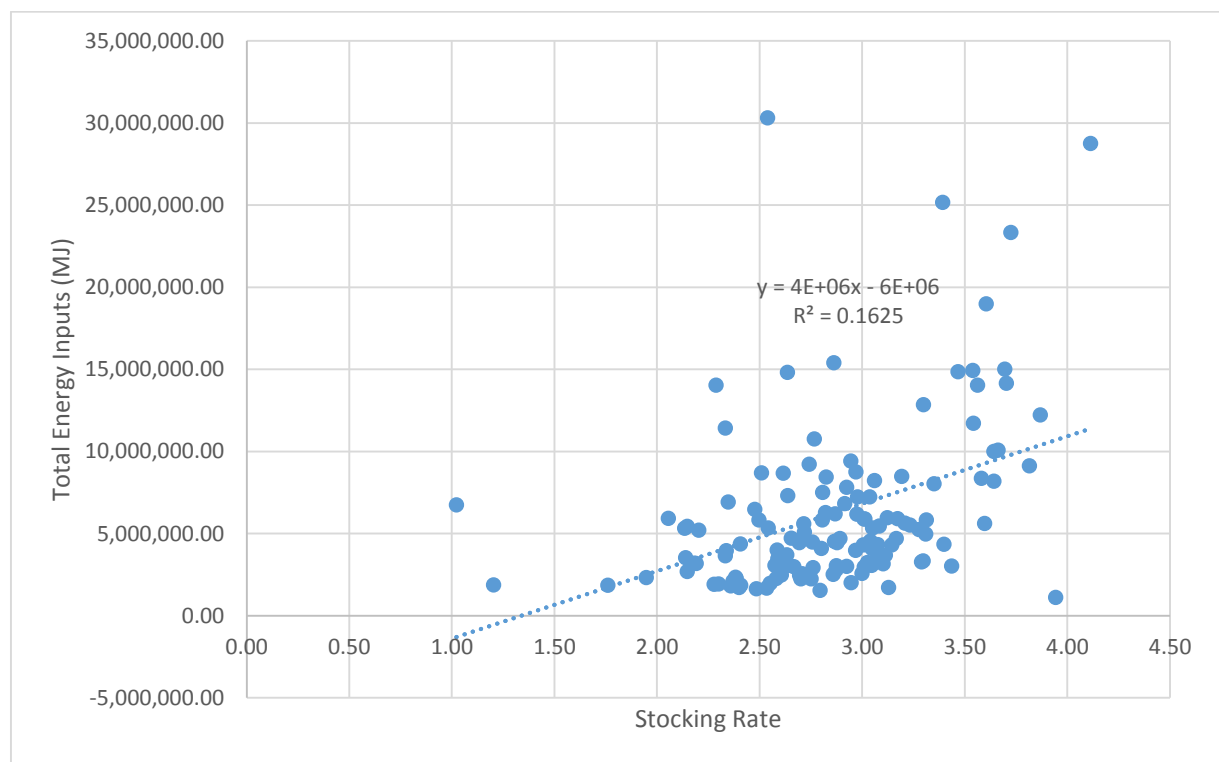


Figure 5: Relationship between stocking rate and total energy inputs

In general, the relationships between the key production indicators and the key energy indicators appear weaker than those simply between the key production indicators. There is a greater diversity in the sample across the key energy indicators, and this has not been explained through relationships to milk solid production, stocking rate, or farm size. Instead, it suggests that there are additional factors at work that can explain the role that various energy inputs play in determining total energy inputs.

Across the next few sections, a variety of factors are analysed in order to examine some of these differences between key production indicators and key energy input indicators.

4.3 Irrigated versus Non-Irrigated

In the representational farm sample, there were 75 non-irrigated farms, and 59 irrigated farms. This represented 56% and 44% of the sample, respectively. Of the irrigated farms, only 9 (15% of irrigated farms, and 6.7% of the total sample) were classified as Low Production System farms (see section 2.3.1), while 31 non-irrigated farms (41% of the non-irrigated farms, and 23% of the total sample) were classified as Low Production System farms. In contrast, for the High Production System farms, 21 (28%) were not irrigated, while 26 (44% of irrigated farms) were. Thus, the role of irrigation is much more prominent for High Production System farms than for Low Production System farms.

In the sample, farms were either classified as non-irrigated, or according to the proportion of their effective milking area that was irrigated. Of these irrigated farms, the only determining factor was if a farm irrigated more than 30% of its effective milking area, or less than 30% of the effective milking area. Additionally, there were 17 farms which did not state an irrigation percentage that were irrigated as determined by expenditure on irrigation. One farm did not state an irrigation percentage and also did not report any expenditure on irrigation, and as such this was classified as a non-irrigated farm. The 17 farms that reported irrigation expenditure but did not declare an effective milking area percentage irrigated have been included in the results for the average irrigated farm, and analysed separately by proportion of total energy inputs (Figure 10). The method of irrigation was not able to be determined from the data provided.

4.3.1 Proportion of Total Energy Inputs on the Average Non-Irrigated Dairy Farm

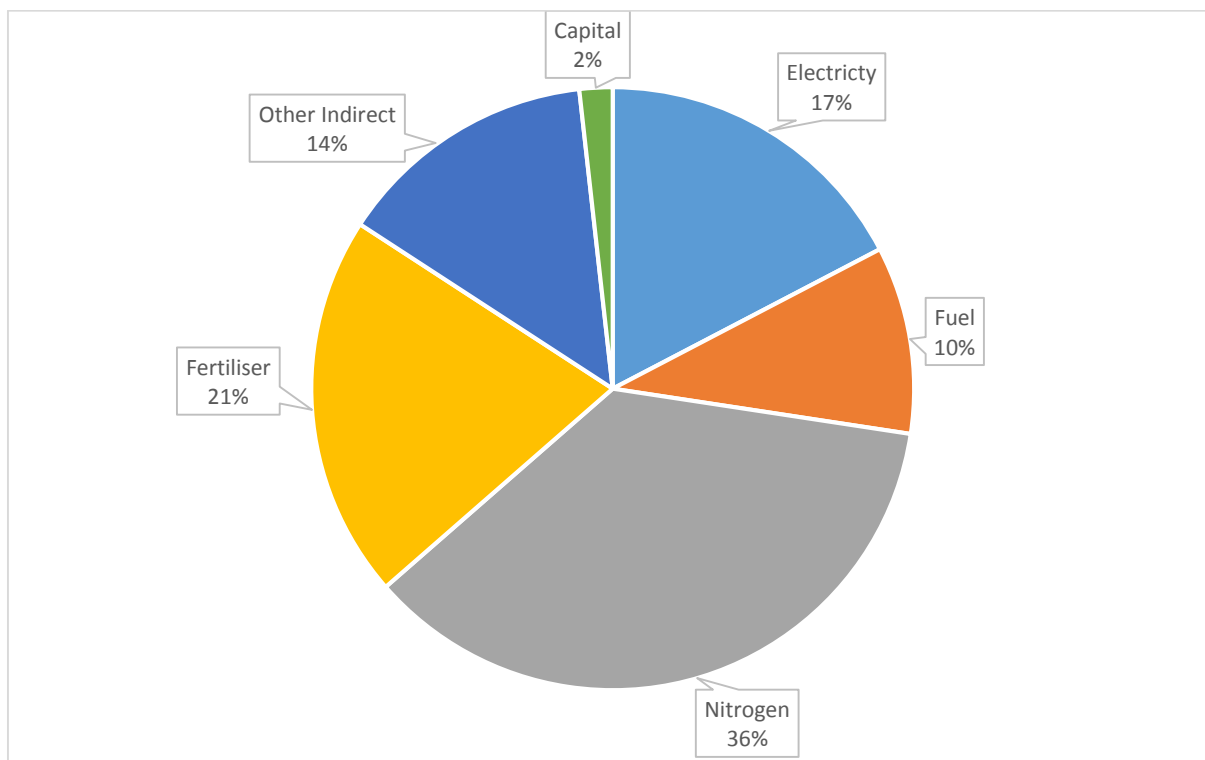


Figure 6: Proportions of total energy inputs on the average non-irrigated farm

The average non-irrigated farm had total energy inputs of 4,500 GJ/yr, and an average size of 173 hectares. Non-irrigated farms had an average stocking rate of 2.63. Non-irrigated farms produced an average of 162 tonnes of milk solids, from an average herd size of 433 cows. All of these values were below the national average.

Fertilisers, and especially nitrogen, made up more than half of the total energy inputs on the average non-irrigated farm, as can be seen in Figure 6. Direct energy inputs comprised barely over a quarter of the total energy inputs, or an average of 1,215 GJ/yr per farm. Capital inputs only made up less than 100 GJ/yr on the average non-irrigated farm, or around 2%.

Of the non-irrigated farms, only two were from the Marlborough-Canterbury region. A further nineteen farms were from the West Coast-Tasman and Otago-Southland regions (7 and 12 farms, respectively). These South Island farms only comprised 28% of the non-irrigated farms, compared to a South Island proportion of 37% for the total sample. The non-irrigated farms from the Marlborough-Canterbury represented just 10% of the total for that region.

In contrast, the average irrigated farm had total energy inputs of 8,420 GJ/yr, and an average size of 193 hectares. These farms recorded an average stocking rate of 3.17. On average,

irrigated farms produced 252 tonnes of milk solids, 55% more than non-irrigated farms. Additionally, irrigated farms had an average of 630 cows, 45% larger than the average herd on an average non-irrigated farm.

Direct energy inputs on the average irrigated farm were nearly double those of the average non-irrigated farm, with electricity inputs nearly doubling. Electricity inputs on the average irrigated farm amounted to around 2,650 GJ/yr. Thus, the average impact of irrigation on farms amounted to an additional 1220 GJ/yr of energy inputs.

4.3.2 Proportion of Total Energy Inputs on the Average Irrigated Dairy Farm

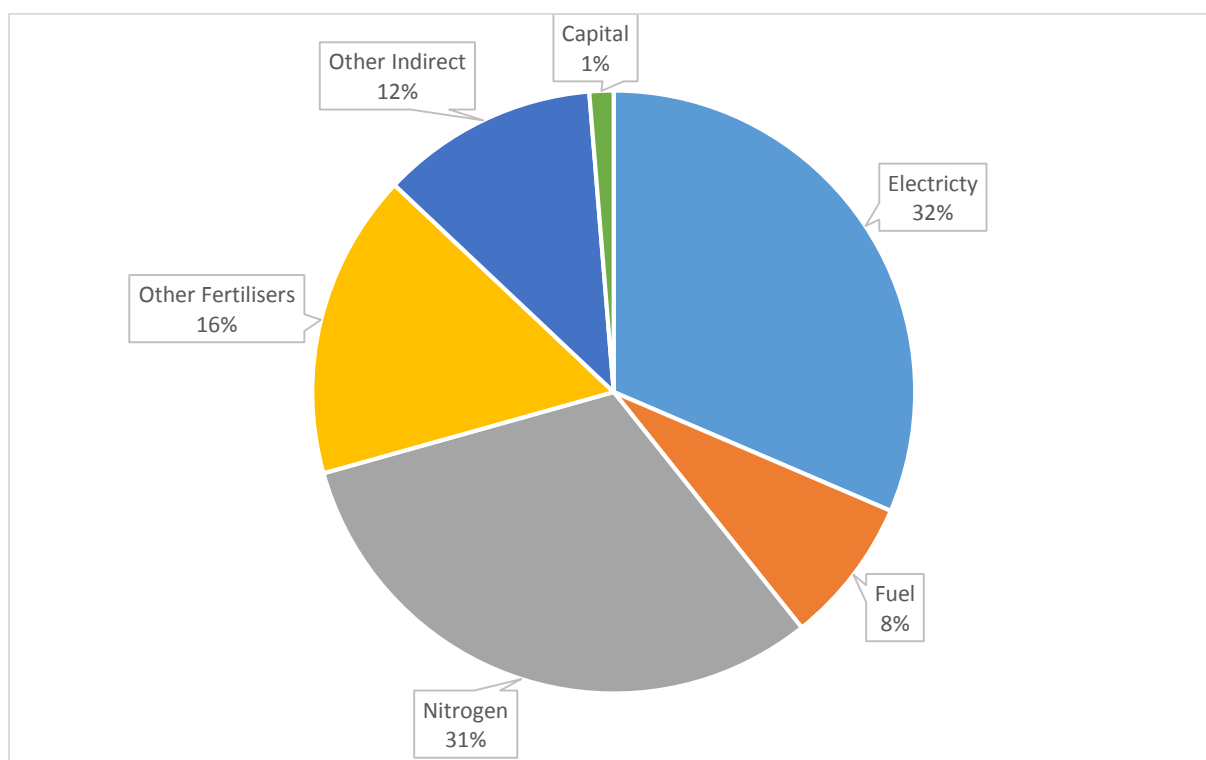


Figure 7: Proportion of average Total Energy Inputs, all irrigated farms

However, this only comprises around a third of the total increase in total energy inputs on irrigated farms. Indirect energy inputs, while declining as a proportion from 71% of the total energy inputs on non-irrigated farms to 59% of the total energy inputs on irrigated farms nevertheless also were higher on irrigated farms. Nitrogen remained a very substantial energy input as a proportion of the total, only marginally smaller than electricity even for the average irrigated farm, although this ratio changed in different irrigation set-ups.

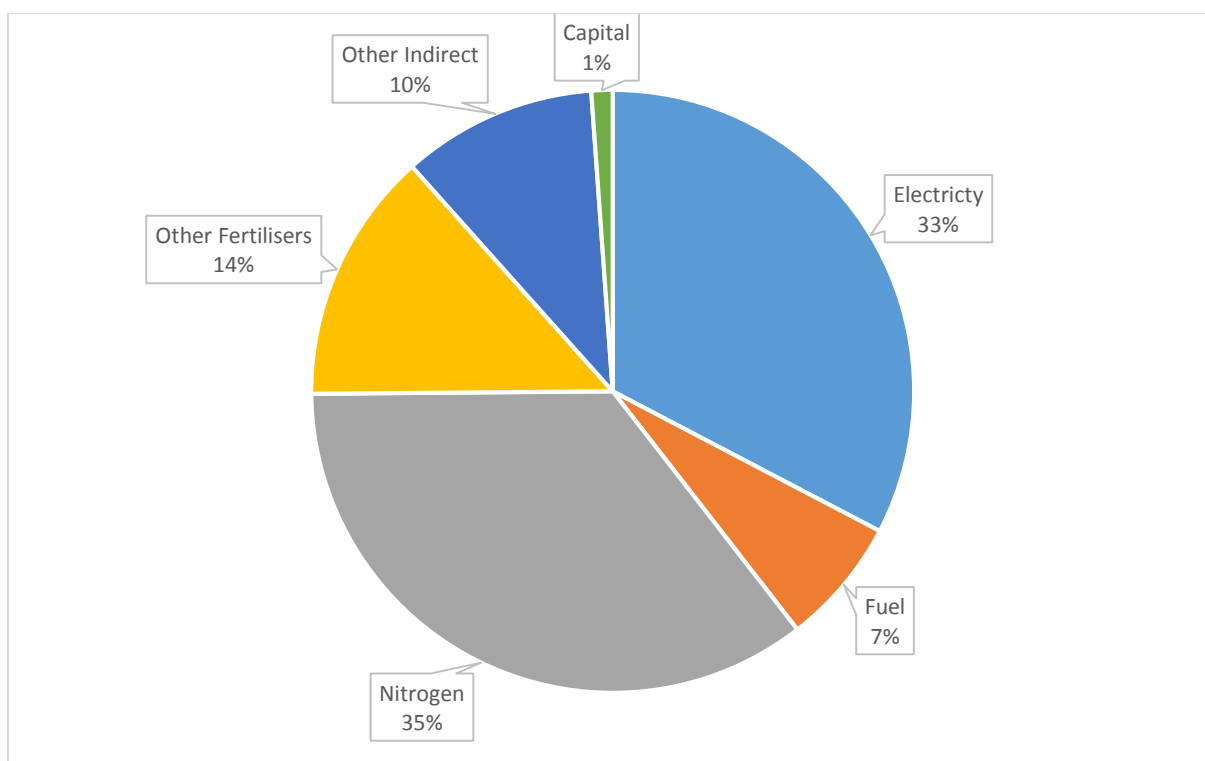


Figure 8: Average proportion of total energy inputs, more than 30% are irrigated

23 farms reported having more than 30% of their effective milking area irrigated. The farms had an average total energy input of 11,635 GJ/yr, nearly three times that of the non-irrigated farms. There was a significant regional bias in these farms, with 14 (60%) were from the Marlborough-Canterbury region, while only 6 (23%) came from North Island regions, with all but one of those from the Lower North Island region. Thus, there is a strong geographical influence on total energy inputs for these high input farms.

However, while electricity made up a slightly larger proportion of total energy inputs, and comprised 3,800 GJ/yr, compared to the average of all irrigated farms, it was still slightly smaller than nitrogen as a proportion of all energy inputs. The energy value of the nitrogen on these farms averaged 4,200 GJ/yr.

The 14 Marlborough-Canterbury region farms had an average of total energy inputs of 13,451 GJ/yr. Within this region however there were several farms with substantially higher total energy inputs, with the highest in this category reaching 25,000 GJ/yr.

For the Marlborough-Canterbury farms, electricity inputs averaged 4245 GJ/yr, only slightly higher than the more-than-30% irrigated sample as a whole. These farms were also much larger on average than both the national sample, with an average size of 233 hectares of

effective milking area, and also larger than the North Island farms in this category, which averaged 199 hectares.

The North Island farms in this category had total energy inputs averaging 8200 GJ/yr, with 2,400 GJ/yr of electricity inputs. This resulted in a lower than average for the category proportion of electricity inputs for these farms, with electricity comprising 29% of the total energy inputs.

In the less than 30% area irrigated category, there were 19 farms. Unlike the more than 30% irrigated category, in this category there were only five farms from the South Island. For the 19 farms represented, the average total energy inputs was 5,800 GJ/yr, with 1585 GJ/yr coming from electricity inputs. This in turn resulted in a different proportion of total energy inputs, shown in Figure 9. For these farms, indirect inputs still amounted to 62% of the total, with electricity a smaller proportion than nitrogen again.

Although the average total energy inputs were smaller, the five farms from the South Island still recorded substantially higher total energy inputs with an average of 7,095 GJ/yr.

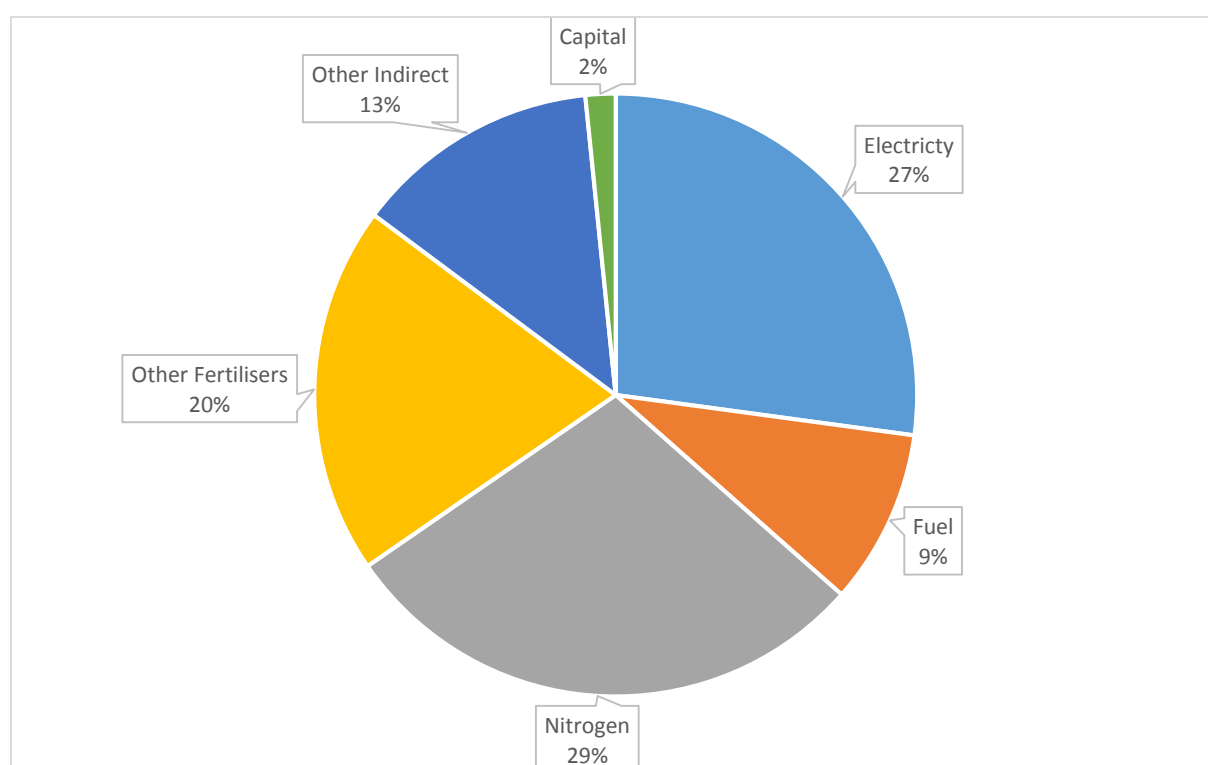


Figure 9: Average proportion of total energy inputs, less than 30% area irrigated

Electricity was a much higher proportion for these South Island farms, making around 37% of the total energy inputs, by far the largest single input. For the North Island farms, the average

total energy input was 5,395 GJ/yr, with electricity inputs only making up around 23% of the total, with nitrogen inputs remaining the single largest input.

The average size of these farms was 166 hectares, lower than the national sample average. However there was regional variation in farm sizes for these farms, with the South Island farms averaging 220 hectares. The South Island farms had higher energy inputs, ranging from 4,500 GJ/yr to 10,100 GJ/yr.

The final category of irrigated farms did not state a percentage of effective milking area irrigated. Of the 17 farms in this category, there were 6 from the South Island, roughly proportionate to the national sample.

The farms of this category had average total energy inputs of 6,928 GJ/yr, with 2,275 GJ/yr of electricity inputs. Unusually, these farms also had substantially larger energy inputs than most of the other irrigated farm categories, in comparison to their nitrogen inputs. Indirect inputs totalled a higher percentage of total energy inputs than direct inputs, despite the much larger than average proportion that electricity had.

The South Island farms had an even higher proportion of total energy inputs from electricity inputs, averaging 39% of the total.

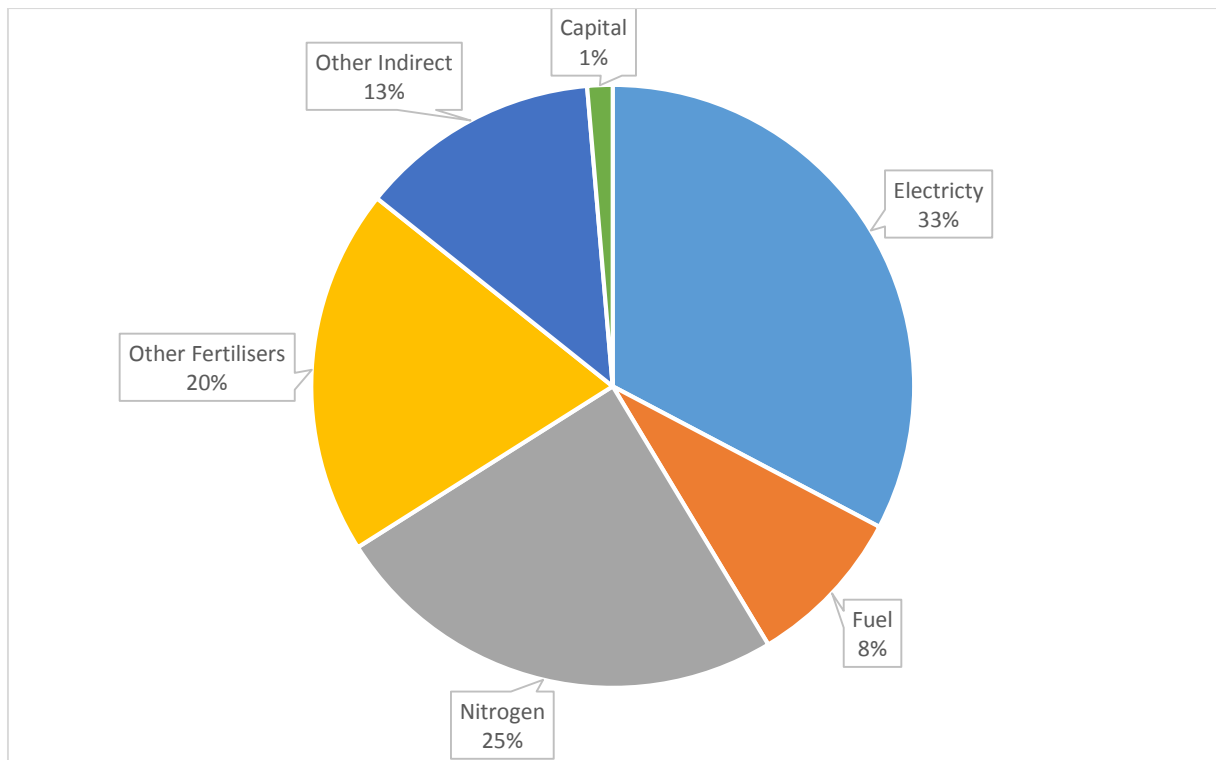


Figure 10: Average proportion of total energy inputs, irrigated area not stated

Thus, there were no groups of farms with less than 52% of their total energy inputs coming from indirect energy sources, with nitrogen the largest single source. For most irrigated categories, the proportion of indirect energy sources was even higher. Additionally, there was regional variation, not only in the distribution of the irrigated farms, but also in the energy inputs, with South Island farms consistently having higher average electricity inputs than North Island ones. Overall, the irrigated farms used considerably more total energy inputs, and this was not just limited to increases in electricity inputs, but was consistent across other inputs as well.

The higher proportion of South Island farms in the irrigated category compared to the national sample, with 47% of the irrigated farms in the South Island, compared to South Island farms forming only 36% of the national sample. However, there was an even more pronounced regional variation within the distribution of the irrigated farms – 90% of the Marlborough-Canterbury region’s representative farms were irrigated, whereas only 23% of Waikato farms had any irrigation.

4.4 Regional Breakdowns

The representative farms were grouped into regions by DairyBase, which uses a slightly different definition of New Zealand's regions than those used in DairyNZ's Statistical surveys. Because of this disparity between regions, there was no attempt to adjust for any regional biases that may have occurred, as it was assumed that DairyBase's distribution would be a good representative sample of regional distributions. As mentioned in Section 4.1, there was a further division into districts by DairyBase; however, these were too small for meaningful analysis as a complete range of farm types; such as irrigated and non-irrigated farms, and a range of differing production systems, were not always present.

4.4.1 Total Energy Inputs by Source and Region

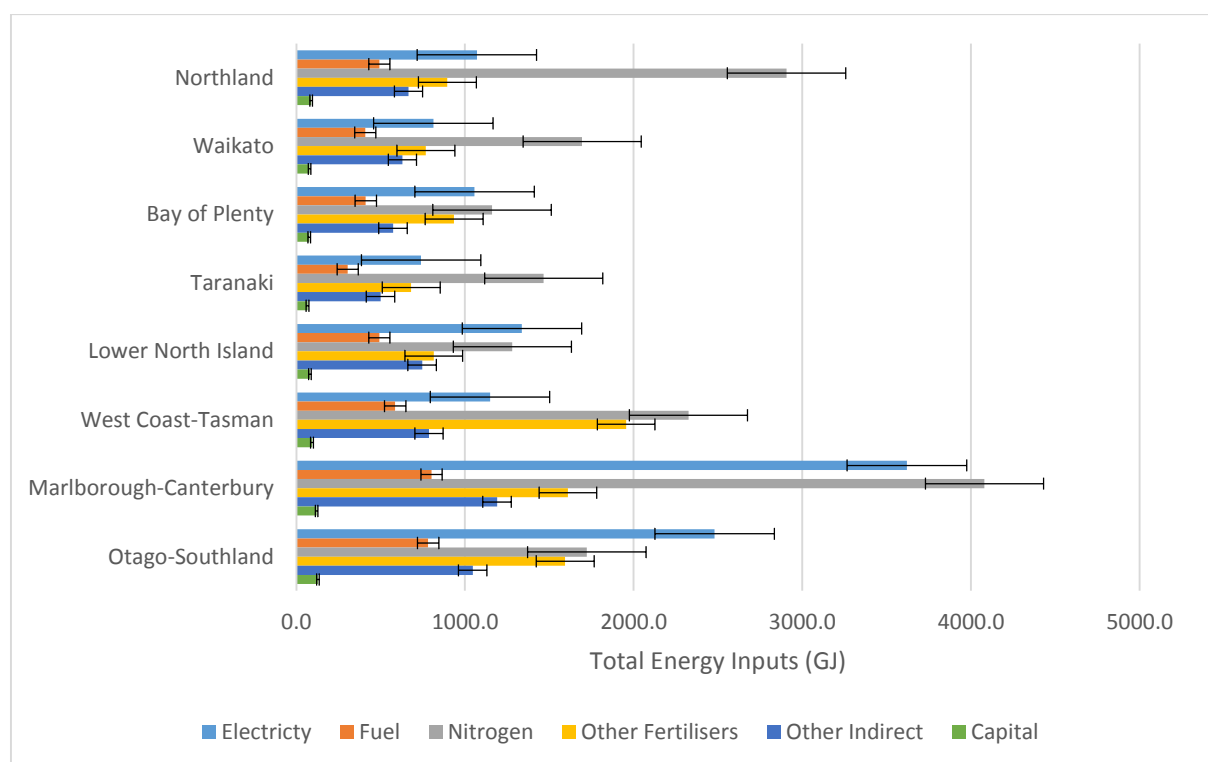


Figure 11: Average Total Energy Inputs, by region and source

As shown in Table 12Table 11: Regional Distribution of Farms, the South Island farms had much higher effective milking areas, production, and herd sizes. This is also reflected in their average total energy inputs, however there are substantial differences between regions in which inputs are most prevalent.

Marlborough-Canterbury farms require significantly more total energy inputs than any other region, with an average of 11,400 GJ/yr of total energy inputs. This gave Marlborough-

Canterbury farms an average Overall Energy Ratio of 0.97, nearly at energy parity. The large energy inputs required by irrigation increases Marlborough-Canterbury's total.

West Coast-Tasman farms recorded an average of 6,895 GJ/yr of total energy inputs, and also recorded the highest OER, at 0.99. Otago-Southland farms recorded the second highest total energy inputs overall, at 7,712 GJ/yr. However, Otago-Southland farms had a much lower OER than either of the other South Island regions, at only 0.66.

The traditional dairying areas of the North Island recorded the lowest overall total energy inputs, with Taranaki recording just 3,757 GJ/yr, the lowest of any region. Waikato, Bay of Plenty, and Taranaki farms all had on average very similar energy profiles, while the Lower North Island recorded higher electricity inputs than any other North Island region. Northland farms on average included an unusually high proportion of energy inputs in the form of nitrogen, as the region has generally been considered a low-input one.

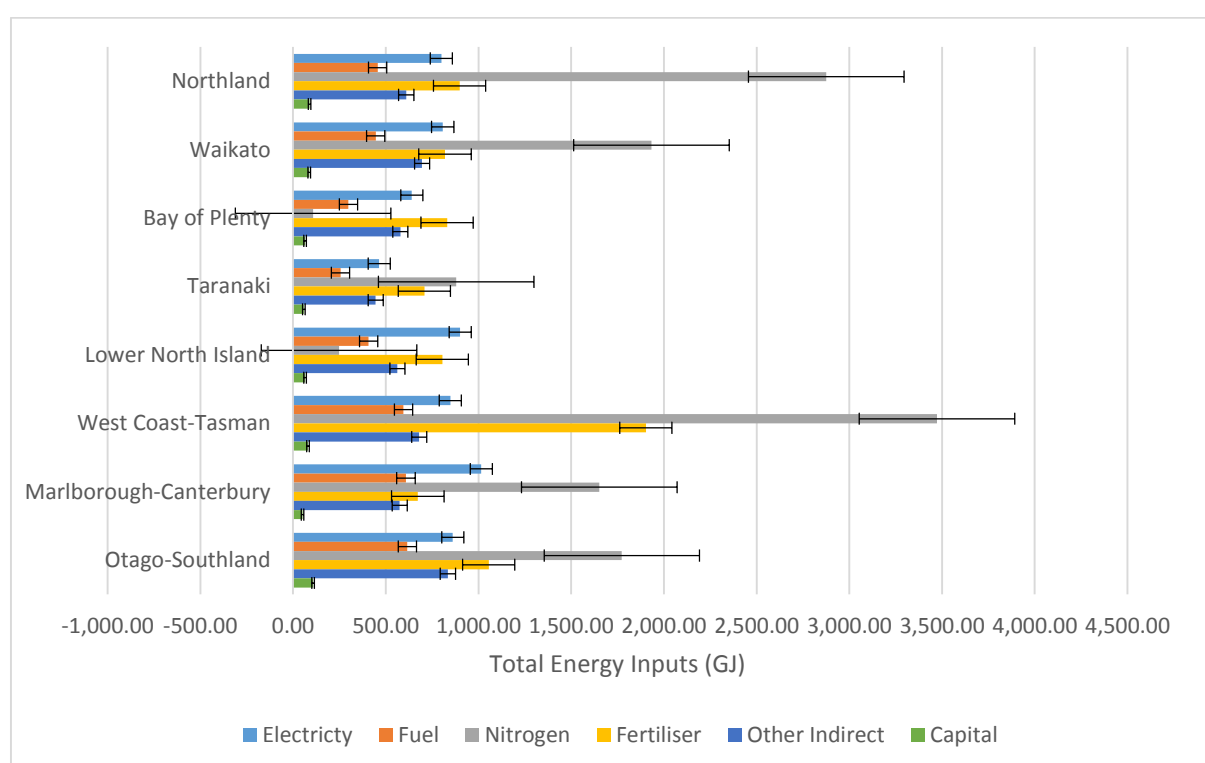


Figure 12: Total energy inputs, by region and source, non-irrigated farms

When irrigated farms are removed from the averages, the geographical balance changes. Most noticeably, Marlborough-Canterbury and Otago-Southland farms that are not irrigated have substantially lower average total energy inputs. However, there may be a bias particularly for the Marlborough-Canterbury region due to the small number of representative farms in this region. West Coast-Tasman becomes the region recording the highest total

energy inputs, with 7,510 GJ/yr, slightly above its whole-farm average. An additional aspect that is masked by the data collection is the substantial variation in nitrogen inputs. As some farms did not separately record nitrogen inputs from total fertiliser inputs, it can appear that nitrogen is significantly below average, most notably in the Bay of Plenty and Lower North Island regions.

The national average OER for non-irrigated farms was calculated to be 0.74. However, there was a large degree of variation between regional OERs. Northland and West Coast-Tasman were both calculated to have OERs above 1, at 1.07 and 1.10 respectively. At the other end of the scale, the Lower North Island region was calculated to have the lowest OER, at 0.45.

The regional breakdown of irrigated farms shows the large total energy inputs used in Marlborough-Canterbury and Otago-Southland. Both of these regions had average total energy inputs above 12,000 GJ/yr. The impact of the increased electricity inputs to these representative farms can be clearly seen in Figure 13. The figures calculated for the West Coast-Tasman region may have a bias introduced by only two farms, in the Tasman area counted, while nitrogen inputs are also merged into total fertiliser inputs.

Of the irrigated farms, there was only one region with an OER above 1; Northland was calculated to have an OER of 1.13, higher than Northland's non-irrigated OER. All the other regions had OERs around 0.75-0.85, giving an average national OER of 0.88.

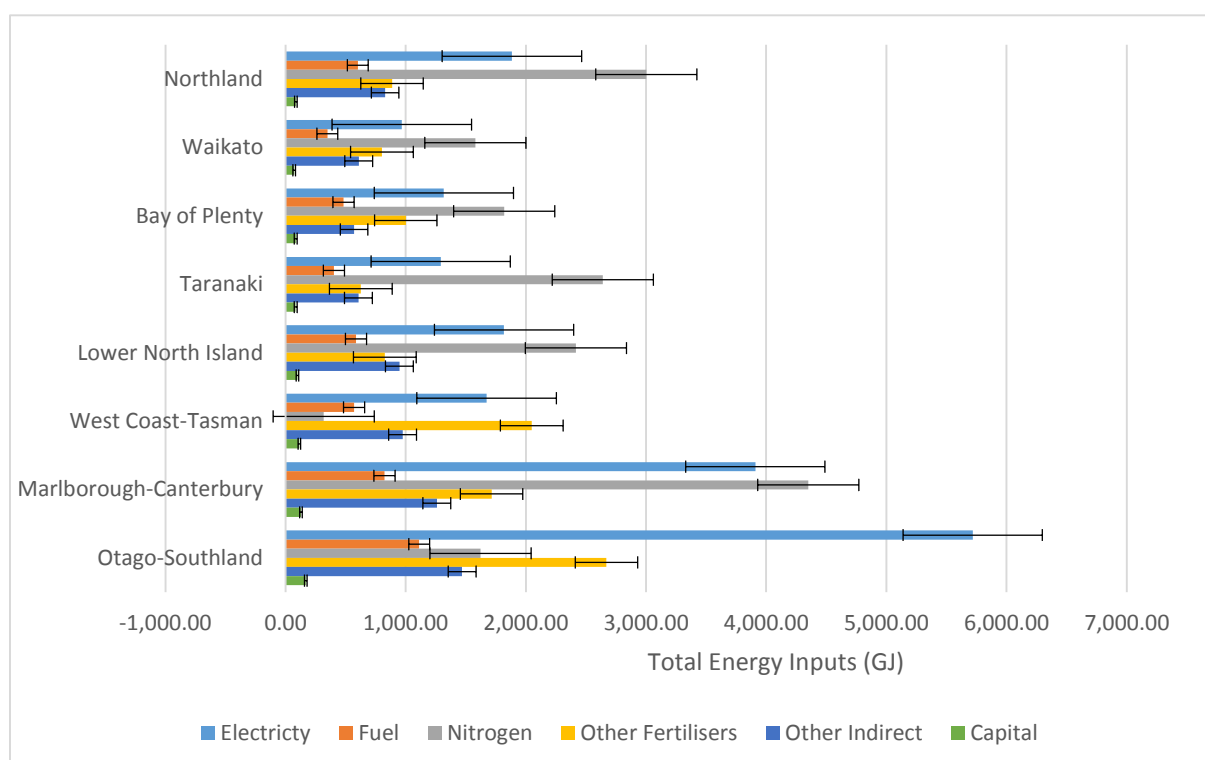


Figure 13: Total energy inputs, by source and region, irrigated farms

Northland also recorded higher average total energy inputs due to increased electricity and nitrogen inputs, compared to other North Island regions. The lower requirement for irrigation due to climate is the likely cause of the North Island and West Coast-Tasman regions recording substantially lower average total energy inputs for irrigated farms.

Despite the geographical disparity in total energy inputs, the different farm sizes and productivities result in varying energy intensities and energy efficiencies.

With the highest average energy inputs, and despite the largest average effective milking area, Marlborough-Canterbury farms recorded the highest average energy intensity of any region, with energy intensity of 51 GJ/ha/yr. The other regions were calculated to have average energy intensities of around 32 GJ/ha/yr, although both the Waikato and Lower North Island regions were calculated to have energy intensities below 30 GJ/ha/yr, at 26.6 GJ/ha/yr and 25.9 GJ/ha/yr respectively.

4.4.2 Total Energy Use per Kilogram of Milk Solids by Source and Region

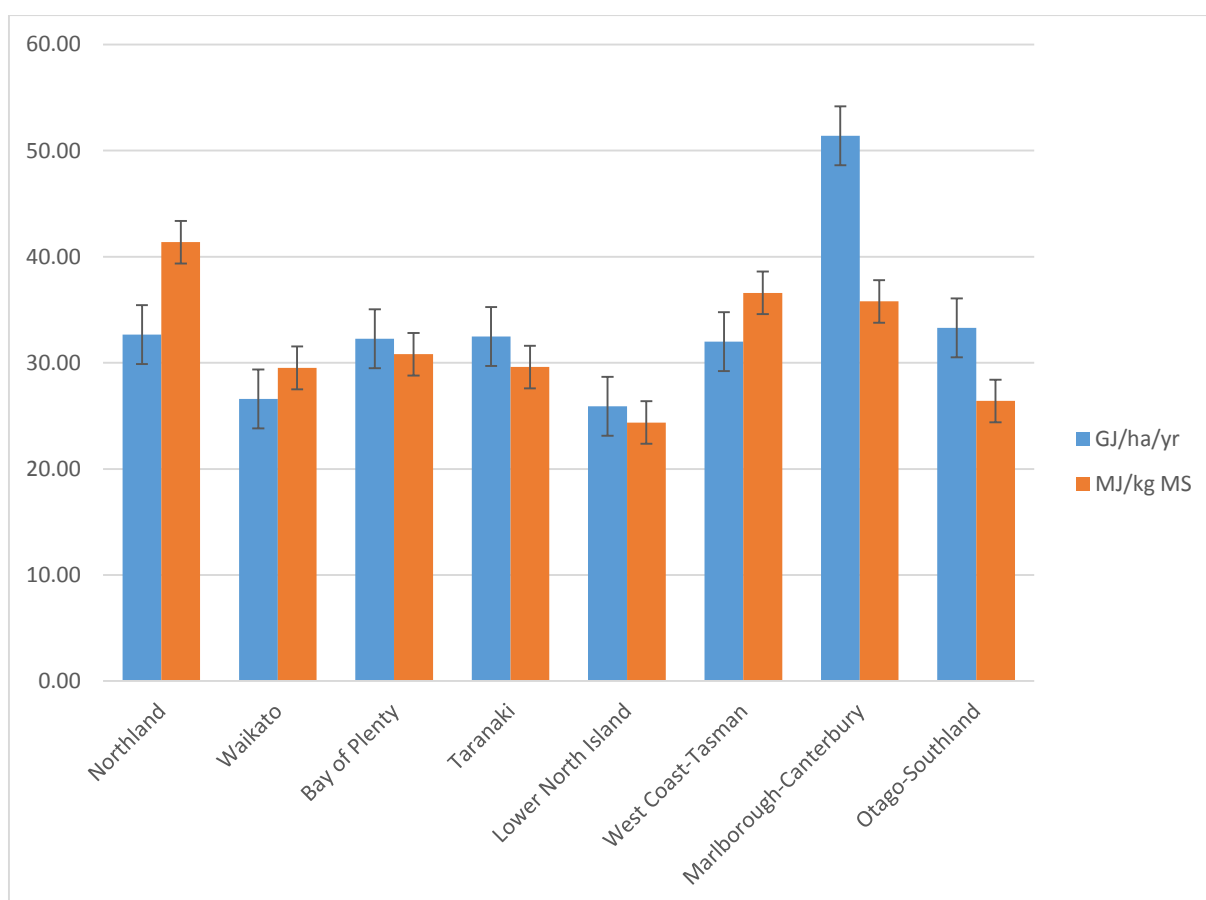


Figure 14: Comparison of energy intensity and energy efficiency by region.

Thus despite the large disparities between total energy inputs, for most regions there are great similarities in both energy intensity and energy efficiency. The OER differs from MJ/kg MS only by a multiplication factor of 36. Only Marlborough-Canterbury, with its very high energy intensity, and Northland with its low energy efficiency stand out as particularly distinctive from the rest of the regions.

4.5 Production System Breakdowns

A development in classifying the New Zealand dairy industry in the past decade has been the five Production System classifications, as described in section 2.3.1. Due to the relatively small sample size of all production system classifications – with some districts only recording one of each production system classification – the representational farms were firstly grouped by DairyBase into three, based on their Production System Classification. Representational farms classified as System 1 and System 2 were grouped as “Low Production System farms”, System 3 farms were classified as “Medium”, and System 4 and 5 farms were classified as “High Production System” farms.

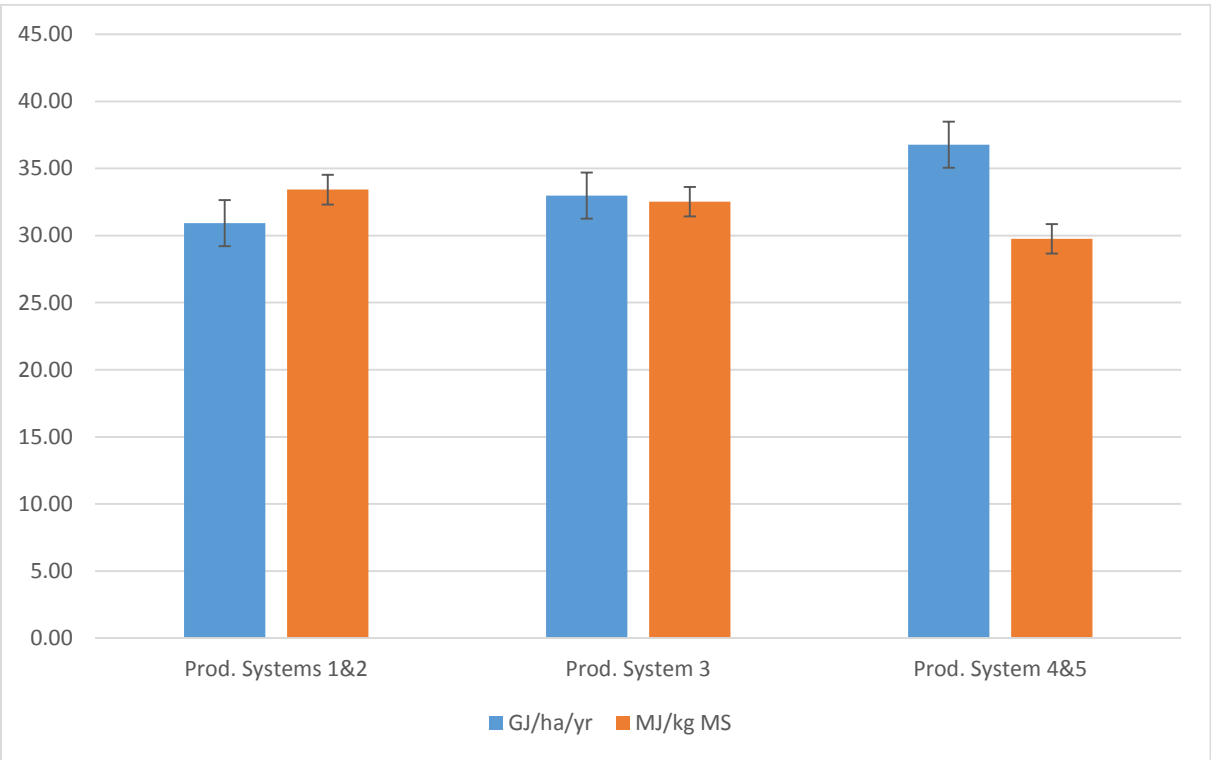


Figure 15: Comparison of energy intensity and energy efficiency across production systems

Across production systems, two broad trends were observed. Firstly, energy intensity increased steadily. Low production system farms had an average effective milking area of 159 hectares, and an average energy intensity of 31 GJ/ha/yr. Low production system farms also

had smaller average herd sizes, with a national average of 403 cows. Medium production system farms had an average effective milking area of 199 hectares, which gave an average energy intensity of 33GJ/ha/yr. Medium production system farms had on average 550 cows. Finally, High production system farms were slightly smaller than the average medium production system farm, at 185 hectares. However, high production system farms had a larger herd size, with an average of 566 cows. This gave an average stocking rate of 3.04, compared to the 2.81 recorded for the average of medium production system farms. As production system is determined by the amount of supplementary feeds brought onto the farm, this allows high production farms to maintain a higher average stocking rate.

The second trend observed was the decrease in OER. Low production system farms were calculated to have the worst OER of 0.85. Medium production system farms were calculated to have an OER of 0.81, while high production system farms were calculated to have the best OER of 0.77.

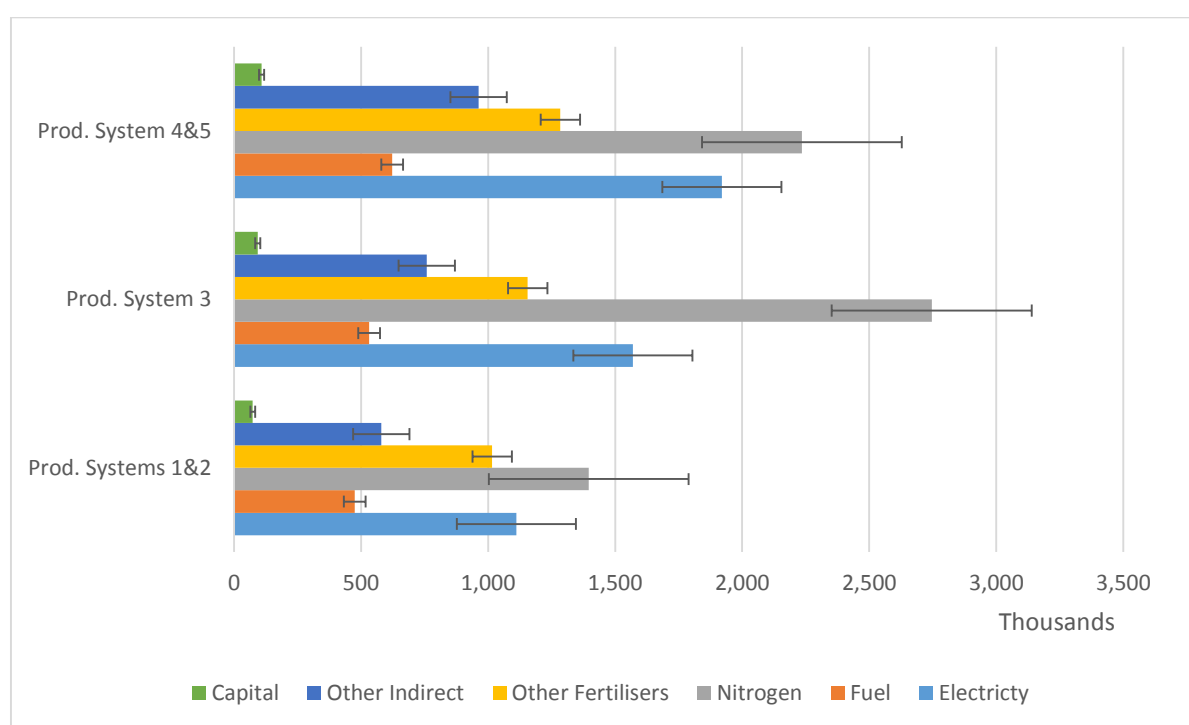


Figure 16: Total energy input sources, across production systems

However, when the energy input sources for each production system type were analysed, it became apparent that the production system determinant – supplementary feeds – was not a key factor in the energy intensity and efficiency of the representative farms.

Electricity inputs were higher as production system classification increased, due to the increased role that irrigation played. The highest electricity inputs were recorded for the high production system farms, with an average of 1,920 GJ/yr. Medium production farms recorded an average electricity input of 1,570 GJ/yr, while the low production system farms were calculated to have an average electricity input of 1,110 GJ/yr.

The other substantial energy input to change was nitrogen. Medium production system farms were calculated to have on average 2,750 GJ/yr from nitrogen inputs. This is likely higher than the high production system farms average of 2,235 GJ/yr due to the production of additional feeds on farm, rather than the importation of supplementary feeds as used by the high production system farms. Other fertiliser inputs were relatively similar between both high production system farms and medium production system farms. The low production system farms had an average combined nitrogen and other fertiliser inputs of 2,250 GJ/yr.

One factor that was not notable for its energy inputs was the single indicator used to determine production system classification. For low production system farms, supplementary feeds made up on average only 118 GJ/yr. On medium production system farms, supplementary feeds were calculated to contribute 178 GJ/yr, while on high production system farms, supplementary feeds contributed 282 GJ/yr.

This suggests that the production system categorisation is not ideal for calculating the environmental impact of farms, and that a more universal factor, such as energy, may be better at describing farms in New Zealand.

Chapter 5

Discussion

5.1 Comparison over time

5.1.1 New Zealand Farms

The study conducted by Wells (2001) is the only other New Zealand-wide survey of total energy inputs to the dairy industry. As described in Section 2.2, Wells' farms were drawn from a similar sample size (150 farms versus 134 farms), and were similarly distributed regionally. Wells used slightly different regional names for three regions to those regions provided by DairyBase. It has been assumed that these regions are the same, and the names of those three regions have been adjusted to match the names provided by DairyBase.⁸ Some differences between the two studies were not able to be verified, so it is assumed that any differences conform to the wider trends of intensification and expansion found. This is supported by the data from DairyNZ's statistics, that found that farm size, herd size, and production all increased substantially across the timeframe of these two studies.

Key Differences

The key difference observed between this study and Wells' is one of scale. In all factors (with one regional exception), all of the key production and energy indicators found in this study are higher. This section demonstrates the evolution in the dairy sector since Wells' report.

In terms of key production factors, the representational farms' regional averages are substantially higher than the regional average farm sizes found by Wells in every case. Some regions have seen larger increases than others, for instance the average farm sizes in most regions increasing by nearly one hundred hectares, while the average Bay of Plenty farm increased in size by only 25 hectares. Marlborough-Canterbury farms, which Wells found to be roughly one third larger than any other region, had a smaller increase than most North Island regional averages, increasing from 175 hectares to 222 hectares.

⁸ Wells' region names were different in three cases: Auckland Waikato, Manawatu Wairarapa, and Canterbury. They are called in this study Waikato, Lower North Island, and Marlborough-Canterbury respectively. Wells also had the region Tasman West Coast, which is here called West Coast-Tasman.

A very large increase occurred in herd sizes, with the national average herd size increasing from 289 cows to 510. This trend was repeated across all regions, for instance the region that Wells found to have the smallest average herd size, Waikato with an average herd size of 201 cows, increased to an average of 434 cows in this study. Marlborough-Canterbury farms, which Wells found to have the largest average herd size, with 470 cows, retained its position with an average herd size of 763. The South Island regions, Otago-Southland, Marlborough-Canterbury, and Tasman-West Coast farms all had much larger increases than the North Island regions, with increases in herd size of 381, 293, and 274 cows respectively. Stocking rates also increased in the three South Island regions. Tasman-West Coast average stocking density increased from 1.9 cows per hectare to 2.5, while Marlborough-Canterbury's stocking rate increased from 2.7 to 3.4 cows per hectare. In the North Island, stocking rates remained steady, with some slight increases (e.g. Northland increasing from 2.2 to 2.4 cows per hectare) and slight decreases (e.g. Taranaki decreasing from 3.3 to 2.9 cows per hectare).

These two factors unequivocally demonstrate the trends of dairy expansion and intensification being driven primarily from the larger increases in the South Island, but also common across New Zealand. How these changes have been reflected in energy terms is discussed below.

Overall Energy Ratios

One of Wells' key energy factors is Overall Energy Ratio [OER], the ratio of energy inputs to energy outputs. The OER for this study was calculated for comparison with Wells' findings. All regions except for Marlborough-Canterbury saw substantial increases in their OERs. The Lower North Island region, which Wells found had the second best OER at 0.50, was calculated to have the lowest OER in this study. However, the Lower North Island's OER increased to 0.64. Otago-Southland, which also had a very low OER had the lowest increase, from 0.54 to 0.66. Taranaki, Wells' lowest OER region at 0.47, saw a very large increase, now calculated as 0.79. Northland farms had the largest increase of any region, increasing from 0.64 to 0.94. Otago-Southland also increased, to nearly energy parity, reaching 0.99 from a base of 0.81. Overall, the national average OER increased from 0.64 to 0.82 in this study. Additionally, of the eight regions, Wells found only Marlborough-Canterbury to be near energy parity, while this study found three regions to be near energy parity. With similar trends, it is possible in the near future that some regions will produce a net energy loss.

Energy Intensity and OER

In every region, there have been substantial increases in energy intensity. This has been led by Marlborough-Canterbury increasing to 52.4 GJ/ha/yr from 36.5 GJ/ha/yr; however, the increases in energy intensity are close to double for most regions. Changes in energy intensity are evidence of the trends towards intensification seen primarily through fertiliser use and irrigation, despite the different story as seen in energy efficiency.

While Wells found that changes to the national average OER had been minor between the 1970s and the 1990s, OER results have significantly worsened between the late 1990s and this study. With the exception of Marlborough-Canterbury, which saw a slight improvement, every region saw substantial reductions in production efficiency, as OER results increased. In particular, the North Island regions, which Wells found had performed well in energy efficiency, saw very large increases in OER. For instance, Northland's overall energy ratio increased from 0.64 to 0.94.

These increase in OER raise concerns regarding energy security and vulnerability, and indicate a worsening in the competitive advantage enjoyed by New Zealand. This is further discussed in Section 5.4.

Despite the predominant trends of energy intensification and increasing OER (meaning decreasing energy efficiency), one region stands out from the rest – Marlborough-Canterbury. Unlike the other regions, Marlborough-Canterbury has seen slight improvements in production efficiency as shown by the decrease in its OER. Canterbury's unique situation is discussed in further detail below.

5.1.2 Canterbury: the most intensive region

Canterbury has the most comprehensive data set of any region in New Zealand. It is also the region that has seen the most intensification in recent decades. Canterbury farms are the largest in size, have the largest herd sizes, and also are amongst the highest-producing. It is in Canterbury then that the best opportunity for tracking the total energy inputs of the dairy industry arise.

Canterbury's intensification can be seen in Table 13, where stocking rates have increased from 1.2 cows per hectare in 1978, to 3.5 cows per hectare in 2012/13. This has been driven in part by large increases in the average herd size of farms surveyed, from an average size of 187

cows in 1978, to 833 in 2012/13. There has additionally been a change in production, and although it should be noted that McChesney's (1979) study only surveyed town milk production farms, this is indicative of the shift in New Zealand's dairy industry markets, to milk solid exports. There were relatively few dairy farms in the Canterbury region at the time of McChesney's survey, with most farms providing town milk supply or contributing to a small butter and cheese industry. The Canterbury region's dairy industry had less than 20,000 hectares until the early-1990s, compared with more than 200,000 hectares today (Pangborn & Woodford, 2011).

The Role of Irrigation

The primary driver in the creation of the modern Canterbury dairy industry has been the availability of water for irrigation. Canterbury was traditionally a dry-land farming environment, and despite some early community experiments, it was not until the 1990s that irrigation began to be adopted on a wider scale. The availability of water opened up what was previously land unsuitable for dairy production, and dairy production offered much larger incomes than those previously available. A combination of deregulation of the financial and agricultural sectors in New Zealand and technological developments in groundwater irrigation systems resulted in a rapid growth in the dairy industry around 1991 (Pangborn & Woodford, 2011).

How Irrigation has transformed the energy profile

The energy studies conducted on the dairy industry thus bookend this dairy development. McChesney's 1979 study shows the energy profile of a dry land, town-supply, small-scale dairy industry in Canterbury. Wells' 2001 study sees the Canterbury dairy industry in a state of transition amid rapid growth, with huge increases in herd size and stocking rate (see Table 13). Finally, this study sees Canterbury dairy farms reaching, perhaps, a saturation point, as all but one of the Canterbury representational farms are irrigated.

Study	Effective Milking Area (ha)	Cows	Stocking Rate (cows/ha)	Milk Solids (tonnes)
McChesney, 1978 (average)	156	187	1.2	67.08
Wells, 2001 (Average)	175	470	2.7	171.8
Barber, 2008 (Single farm)	181	670	4.1	274.6
Latham, 2010 (Single Modelled Farm)	210	705	3.4	280.01
This Study (average)	240	833	3.5	351

Table 13: Key Production indicators, Canterbury Farms from all studies

All three of these studies have similar samples for Canterbury. McChesney surveyed twelve Canterbury farms, Wells surveyed 24 farms, and this research collected 17 representational farms from Canterbury. The Marlborough farms included in the Marlborough-Canterbury region provided by DairyNZ were removed from this analysis, which slightly reduced the energy intensity, and slightly improved the energy efficiency when compared to Table 12.

In addition to these studies, there are two other studies that have been conducted on Canterbury-based farms (see Section 2.4.3). Barber (2008) conducted an energy inventory and analysis on the Lincoln University Dairy Farm (LUDF), while Latham used a Ministry of Agriculture Pastoral Model farm. Both of these studies however appear to have unusual results when compared to the wider surveys and this research.

Barber's 2008 study of the Lincoln University Dairy Farm was based on the 2006/7 season. Barber's report had much better OER of 0.55 which is considerably lower than the average Canterbury OER of 0.99 that Wells found for the 1997/8 season. However, in spite of its low OER value, Barber found that the LUDF had a higher energy intensity than the average Canterbury farm from Wells' research. Barber's results however are substantially different also from the findings for the average Canterbury farm in this study. However, while the LUDF may contribute to the intensification of the Canterbury dairy industry, it is not necessarily representative of it.

Latham's (2010) results do not agree with the findings of this study, nor with that of Wells. Latham's research found both energy intensity and energy efficiency were substantially different to that of Wells' Canterbury farms. It is unlikely however that energy intensity would have reduced slightly in the years between Latham's and Wells' respective studies, given the trend both nationally and in Canterbury towards intensification.

When comparing the findings of Latham to this study, this difference is accentuated further. This study found that energy intensity levels in Canterbury are substantially higher than those reported by Latham, and that energy efficiency is similarly different. Latham's results do not show an intensification in energy inputs, despite showing increases in farm size, milk solid production and other factors. It is possible then that Latham's model was not in fact a good representation of a Canterbury farm, despite coming from governmental sources.

Study	Energy Intensity (GJ/ha/yr)	OER
McChesney, 1978 (average)	9.1	0.57
Wells, 2001 (Average)	36.5	0.99
Barber, 2008 (Single farm)	43.4	0.57
Latham, 2010 (Single Modelled Farm)	33.2	0.65
This Study (average)	51.3	0.91

Table 14: Comparison of Canterbury farms

Excluding the single farm studies of Barber and Latham, the transformation of the Canterbury dairy industry is one of distinctive intensification. Energy intensity increases dramatically over the decades, from 9.1 GJ/ha in 1977-78 to 51.3 GJ/ha in 2012-13, an increase of 464%. However, the rate of change has slowed somewhat, as the increase between 1977-78 and 1998-99 was much more rapid than the change between 1998-99 and 2012-13. This may be suggestive of energy intensity slowing due to a reduction in the production gains from further increases in energy intensity.

While energy intensity has seen a very large increase, OER is much more stable, and may in fact be improving. McChesney calculated an average OER of 0.57, while Wells calculated an average OER of 0.99. This study has found an improvement in energy efficiency for Canterbury

farms compared to Wells, who found that Canterbury farms were nearly at energy parity; however, this study has found that overall energy ratio has improved to 0.91.

Therefore, despite the very large increases in energy intensity calculated for Canterbury across these three studies, they do not necessarily imply an increase in OER, (in other words energy efficiency remains the same). Canterbury farms have, thus far, demonstrated that energy efficiency can improve over time (the decrease in OER) even when energy intensity increases considerably. However, despite this, modern Canterbury farms are still much less energy efficient than they were in the 1970s.

The next section explores the key drivers of energy input change.

5.2 Why has Change Occurred

There are two clear drivers of the evolution of the dairy industry's total energy footprint. Both of these can be attributed to the intensification and the demand for increased production.

The first primary driver of energy change is nitrogenous fertiliser use. From the literature (Judge & Ledgard, 2009), it can be seen that there has been a recorded increase of nitrogenous fertiliser applications in the Waikato. However, the results from the energy data suggest that this is not by any means confined to just that region. Instead, there have been large increases in nitrogenous fertiliser use across the nation.

Wells' National Average farm had an indirect energy intensity of 7.6 GJ/ha/yr. In contrast, the average of the representational farms found that indirect energy intensity had increased to 21.7 GJ/ha/yr. While Wells' did not state the proportion of indirect energy intensity that fertiliser made up, this study found that approximately 80% of the indirect energy inputs came from fertilisers. If the same proportion is assumed for Wells', then the energy inputs from fertiliser are 6.1 GJ/ha/yr, while this study found 17.4 GJ/ha/yr came from all fertiliser inputs. This three-fold increase is a clear driver of energy input change, and the same changes were seen by Wells when comparing his results with those of McChesney.

The second driver is irrigation. Of Wells' surveyed farms, only 25%, nationally, were irrigated. In this survey, the proportion of irrigated farms was 44%. It does not at this time appear possible to validate either of these figures, but it is clear that the growth in the dairy industry has in the previous two decades largely come from the South Island, and most of those farms

are irrigated (Pangborn, 2012). There are also clear increases in irrigation totally for New Zealand (MacLeod & Moller, 2006). Of the Canterbury farms in the representative sample, 90% were irrigated. However all regions featured irrigated farms, and the increase nationally is likely to be part of a wider trend towards increased irrigated production.

Irrigated farms were calculated to have nearly double the total energy inputs compared to non-irrigated farms. Additionally, there were increases in both total energy inputs and electricity inputs between Wells' survey and this study. Wells' average non-irrigated farm had a total energy intensity of 16.9 GJ/ha/yr, while the average irrigated farm's total energy intensity was 30.6 GJ/ha/yr. Electrical energy intensity was found to be 3.4 GJ/ha/yr for non-irrigated farms, and 12.2 GJ/ha/yr for irrigated farms.

In this study, non-irrigated farms had an average energy intensity of 26 GJ/ha/yr, compared to irrigated farms, which had an average energy intensity of 43.6 GJ/ha/yr. Electricity inputs for non-irrigated farms were calculated to be an average of 4.5 GJ/ha/yr, while the same for irrigated farms was calculated to be 13.5 GJ/ha/yr. Even excluding the physical increase in irrigated farms, irrigated farms in general have clear increases in total energy intensity and in electrical energy intensity, over the years between Wells' survey and this study.

Both of these factors have driven the large increase in total energy intensity between Wells' study and this study. However, they are also the main drivers of increased production between McChesney's survey and Wells'. Considering OER, productivity was increased at roughly the same rate as inputs were increased, resulting in roughly the same OER. However, there appears now to be a disconnection emerging between additional inputs and increased productivity, nationally. At least, increased energy inputs have not delivered the same increase in production, but rather a lesser one. This is true in all regions except Canterbury. The implications of this are discussed further below.

5.2.1 Explaining Canterbury's change

As previously stated, Canterbury experienced a slight improvement in energy efficiency, unlike all other regions. While this is an area that likely requires further research to ascertain whether this result can be continued, and whether it is possible for Canterbury farms to continue to reduce OER, some potential answers may include a change in the technology and practice of irrigation.

As seen in Table 6, there is a clear difference between different irrigation systems. Electricity savings of several thousand dollars per year have been reported by farmers switching to more energy efficient irrigation systems (McChesney et al., 2004, p. 29; Pangborn, 2012, p. 142). Part of this energy saving will not only be farmer preference, but also increasing regulations around water access, in particular the shift from deep groundwater wells to river and stored water. Irrigation practices may also have an impact, as increased knowledge and monitoring of irrigation becomes utilised.

While this study was not able to measure particular changes in technology, it may be possible that a broad trend has been recognised in the results, without reference to any particular farms.

Regarding fertiliser use, the use of nutrient budgeting, together with increased awareness, and improved precision in fertiliser applications relative to production may also play a role in the improvement of energy efficiency seen in Canterbury.

5.3 Limitations of Results

There are several aspects of concern regarding the limitations of the results of this study. The conversion of financial data to energy data on this scale cannot always be verified, and although there was some validation of results from the pilot study conducted on LUDF, the contrasting results from Latham's study of a model Canterbury farm with the results from both Wells and this study suggest that there may be aspects of energy inputs masked by financial data.

5.3.1 Limitations of energy coefficients

The largest limitation with energy analysis is the reliance upon energy coefficients which may not fit a 'one-size fits all' approach. While these energy coefficients have been drawn from the available literature, there is no way to verify their accuracy. In many cases, tracing certain energy coefficients through the literature will lead to the same coefficient appearing first in the 1970s. Some come from international sources, or are means of several different sources both national and international, which may have wide variations in range.

While there has been recent work to address this (see section 2.4.2), there are still potentially substantial variations between differently sourced inputs. For instance, nitrogen fertilisers, as reported by Ledgard et al. (2011), have different total energy requirement that vary by a third.

The energy coefficient used in this study is an average of the sources reported by Ledgard et al. (2011), and is similar to the coefficient used by Wells (2001). However, for other fertilisers, for instance lime, only a single source was used, and it is unclear if that is representative for all of New Zealand.

The uncertain reliability of the energy coefficients suggests a degree of uncertainty in the results. The energy coefficients used allow for comparability across other studies in New Zealand, and should be comparable to studies internationally. The lack of updated figures in some categories reflects some of the research effort required to calculate these. Unfortunately, there remains a lack of robustly analysed energy coefficient data available for New Zealand. This problem is a global one, that is not limited to energy analyses, and is common across many life cycle analyses and related studies (Curran, 2012).

Wells did conduct an initial analysis of the sensitivities of his results, looking at the major factors of nitrogenous fertilisers, electricity, and fuel. Wells reported variations of ± 15 percent for nitrogenous fertilisers, ± 10 percent for electricity, and ± 10 percent for all fuels. With these figures as energy indicators, Wells reported that the total Overall Energy Ratio (OER) varied by approximately ± 10 percent. Wells also simulated sensitivities of ± 20 percent for an unspecified number of other coefficients, including: bought-in feeds, and vehicles and implements, which represents the next most energy intensive indicators. However, these only added around ± 1 percent to the total variation. Thus, Wells concluded that the overall analysis was relatively insensitive to errors in estimation of energy coefficients and that the variation in energy coefficients was less than the expected error of Wells' mean OER (Wells, 2001, p.68).

Internationally, a study by Vigne et al. (2012), which explicitly focused on uncertainty analysis in the energy analysis, used a Monte Carlo simulation of 30,000 sets of energy coefficients on two clusters of French farms. These energy coefficients were drawn from a wide range of international literature spanning several decades. Vigne et al (2012) found that the results of the simulation “represents a variation around the mean of $\pm 16\%$, and $\pm 17\%$ ” respectively, for each provincial farm group (p.187). It is not clear what result would have been produced had the simulation been limited to more recent and region-specific energy coefficients.

There remains uncertainty around New Zealand-specific data. For example, Ledgard, Boyes, and Brentrup (2011) provide the most recent available data on key energy inputs such as fertilisers. Nitrogenous fertilisers were found to have a variation of ± 10 , which is similar to

that found by Wells (2001). For lime however, only one New Zealand data source was available. The limited availability of data means that it would not be possible to accurately assess the statistical variation for New Zealand energy coefficients without further data becoming available. However, given the above examples of Wells (2001), and Vigne et al (2012), it is assumed that the variation likely in this thesis are similar, and as such the risk of erroneous energy coefficients substantially altering the results is assumed to be quite low. The restricted time frame for data analysis in this research also precluded further analysis of potential uncertainties.

Irrigation was a factor identified by Wells for which the DairyBase data introduces a significant limitation. McChesney et al. (2004) found that different irrigation types resulted in significantly varying energy results (see Section 2.4.2); however, DairyBase does not distinguish between the methods of irrigating. Without this data, it has been assumed that all irrigation costs are equal, but that the different expenditures of irrigation will bear out some measure of this variation. The lack of capital data regarding irrigation type is an important limitation, as it will prevent any further accuracy. There appears to be a trend towards centre pivot irrigation systems and other more modern forms of irrigation for a variety of reasons, including the ability to better control water applications and as part of a shift from drought prevention to optimised production (Pangborn, 2012, p. 139). Another shift seen in Canterbury has been a shift from pumped well water to river and stored water supplies (Pangborn, 2012, p. 142). The impact of changing pump pressure and pumping distance is significant for the energy required for irrigation

Likewise, there is another limitation around capital energy data availability. While capital energy is only a small proportion of the total in all previous studies, there are differences in the energy requirement of various capital inputs, such as machinery and plant. In particular, the total energy inputs to dairy sheds is an area that would be very informative for future analysis; however, there is not currently a way to gain dairy shed information from the data available through DairyBase.

Though this has previously been done with individual farm audits, it was not possible to do so with the DairyBase data as the data provided were for representational farms. However, the incorporation of this data into the DairyBase collection system should not be hard to do. This capital data, as well as information on machinery and irrigation type, would allow this study

to go beyond reporting the broad trends, and allow for specific on-farm actions to improve energy efficiency.

However, while this study did not have the data to exactly determine capital inputs, the capital inputs drawn from the available DairyBase data do represent a similar proportion of the total energy inputs as those found in previous studies. Thus, while improved capital data is a desirable factor, it is not a requirement for a national level energy analysis.

5.3.2 The role of supplementary feeds as farm classifiers

Finally, a limitation appears to be the role of supplementary feeds as the sole classifier of dairy farms in New Zealand (see section 2.3.1). The results of this study demonstrate that the total energy of supplementary feeds are not the main factors of energy consumption (see Figure 16), and that supplementary feeds are in fact a minor factor in the energy intensity of farms.

This is not entirely unexpected, as supplementary feeds are used as can be seen in section 4.5. There is a much smaller difference between the production system types in their energy intensity than between other significant factors.

Average energy intensity is significantly different between the average of low and medium production system farms, but not between the average of medium and high production system farms.

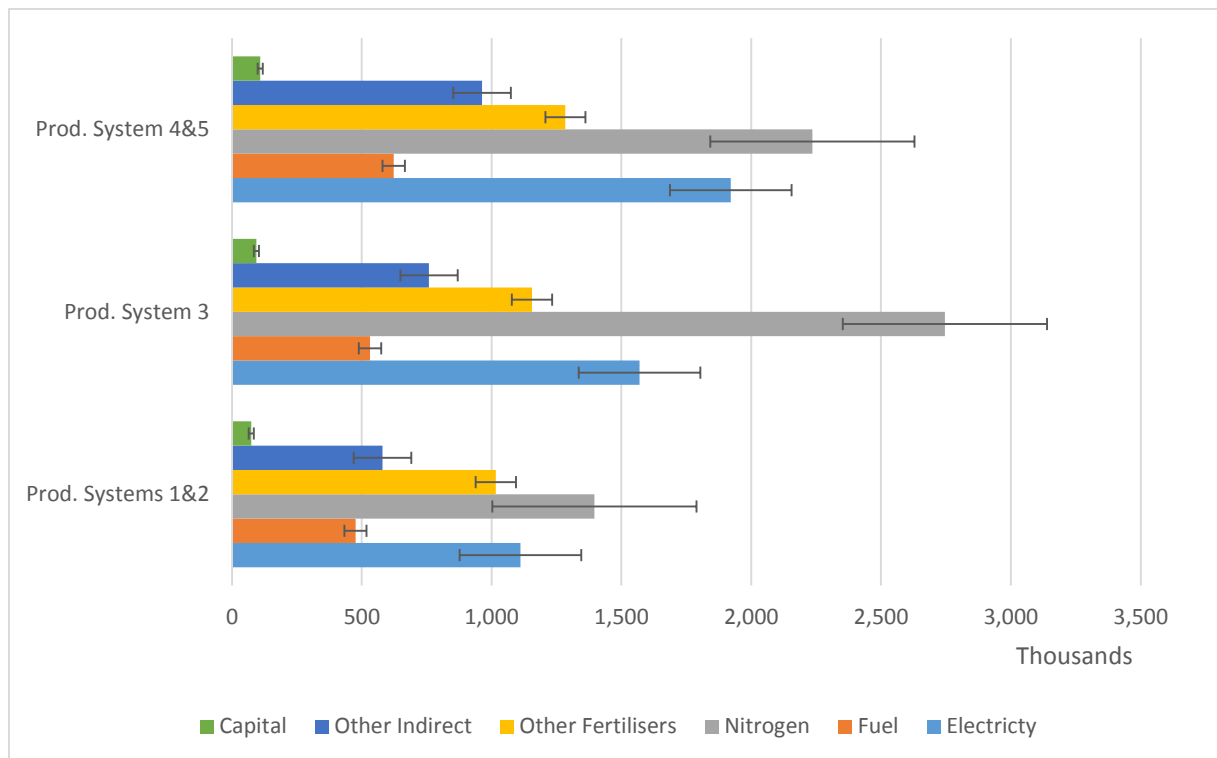


Figure 17: Comparison of energy intensity across production systems

Thus, it is likely that using supplementary feeds as an indicator of a farms production method is not an informative one for determining anything other than the amount of supplementary feeds used by a farm. (again, just take off the “.00” of the axis labels)

Instead, more may be gained from the use of energy as a classifier, with the option of using energy intensity, energy efficiency, or overall energy ratio as a more informative classification for dairy farms in New Zealand, allowing farmers to rapidly compare key energy factors with a single indicator.

5.4 New Zealand’s Competitive Advantage Reviewed

New Zealand’s agricultural economy is based on its export trade and its competitive advantage of efficient production. In the early 2000s, the issue of ‘food miles’ became politically important especially in the United Kingdom as concerns arose around the environment footprints of long-distance imports to Europe. Two studies in particular investigated the comparative environmental footprints of New Zealand agricultural exports and domestic production in the United Kingdom, including dairy. The dairy section was largely drawn from Wells (2001), and thus is comparable to this research. The Saunders et. al. (2007; 2006) studies added to a base energy productivity of 22 MJ per kilogram of milk solids produced for New

Zealand a transport energy input of 2 MJ per kilogram, including the additional energy costs of shipping to the UK. Thus, New Zealand's 2006 calculated export Overall Energy Ratio for dairy was 0.64. This compared extremely favourably to the United Kingdom's calculated OER of 1.26 (Saunders et al., 2006).

The results of this study have calculated the current New Zealand average OER of 0.82, which while substantially higher, and thus less efficient than the results from Wells' study, are still significantly lower than the United Kingdom data compiled by Saunders. Even when assuming the same transport energy, the current New Zealand dairy production only requires 57% of the total energy inputs of the United Kingdom of nearly a decade ago.

Including the outlying Swedish figures (Table 7), the European average OER is 1.24. Excluding the Swedish data, the average is 1.04. The conventional Australian farms also have an average of 0.95, while the United States farms have an average OER of 2.4.

Nation	OER
European Average	1.04-1.24
USA	2.4-2.8
Australia	0.95
This Study: New Zealand	0.82
This Study: Canterbury Region	0.91

Table 15: Comparison of Energy Efficiency amongst Key Competitors

There are some signs that the New Zealand dairy industry is losing the degree of its advantage. Wells (2001) found that while New Zealand farms were significantly better in energy utilisation than farms from the United States (with a national average Overall Energy Ratio of 0.59 for New Zealand compared to 2.4 for the United States), they remain so in this study.

However, New Zealand's Overall Energy Ratio has increased narrowing the competitive advantage that New Zealand had. Canterbury farms were found by this study to have an OER similar to that of Australia, and Northland region farms had an OER above those found for Australia.

This places New Zealand production in a more vulnerable position than previously, if New Zealand production continues to reduce its energy efficiency.

Chapter 6

Conclusion and Research Implications

The aim of this study was to calculate the total energy inputs required for the New Zealand dairy industry, and to explore the main drivers of change over the previous few decades. Energy research in New Zealand is an area that is still under-researched, and while the dairy industry offers a well-organised and institutionalised industry with good data coverage, there is very little focus on energy issues.

The New Zealand dairy industry has performed well in energy terms over the previous decades, but it appears that energy intensity is increasing as farmers strive to produce more for a growing international market. While the increasing energy intensity of New Zealand dairy farms is a concern, a larger concern is the reduction in energy efficiency. New Zealand has traditionally held a strong position as a very energy efficient agricultural producer, and that has allowed this nation to defend itself politically against challenges such as the food miles debate.

While New Zealand still performs well, albeit in the absence of comprehensive international data, the evidence is that New Zealand dairy farms can perform more efficiently. There will likely be further pressures on New Zealand internationally to retain its efficient status in an ever more environmentally conscious international market. New Zealand has enjoyed a huge competitive advantage in energy terms, but a lack of energy research in the area has meant that there is still limited understanding of the industry's energy profile. To that end, this study finally makes some recommendations towards increasing the body of knowledge around energy analysis and New Zealand agriculture.

6.1 Recommendations

This study has been able to draw on financial data from existing industry sources, and convert that financial data into an energy analysis. This suggests that a monitoring programme should be relatively straightforward to establish, while tracking the further evolution of the dairy industry and allowing for specific areas of energy use improvement to be identified.

In order for a monitoring programme to be most effective, some areas of research require further attention:

- Irrigation appears to be the most major area where there is a serious lack of data. Irrigation systems appear to vary significantly between individual farms, and no accurate estimate could be found. Instead, this study used electricity as a proxy for all irrigation systems. Further investigation into the energy inputs required for irrigation would solve this area of uncertainty.
- Capital energy is an area where DairyBase data is not currently verifiable. While the best attempts have been made with the current data available, there was no way to establish the capital energy of existing capital on farms. While this is a relatively small part of the total picture, it will still provide valuable information about the total energy inputs required. The expansion of farm monitoring to better include capital inputs and to undertake even irregular surveys of capital in place would greatly aid this.
- Further, the energy coefficients available may require updating, or uncertainty analyses on the available coefficients conducted. Many data come from international sources, and may not be accurate for New Zealand, and many data appear to have been developed in the 1970s, so may no longer be totally accurate. The energy coefficients are the largest area where there is uncertainty, and will likely require long and detailed investigation, but should provide immense benefits in the form of accurate research.

There are also several aspects of energy analysis which merit further research:

- There is a lack of comprehensive international studies at the national level. Energy analysis offers a way to benchmark and compare aspects of the environmental footprints of farms globally. This will be important for New Zealand in order to maintain its competitive advantage, and quantify and market its competitive market overseas. There is increasing evidence that customers in key export markets, including China and India are willing to pay much higher amounts for food products with low environmental impacts (Miller et al., 2014).
- While this study looks on-farm, there is immense scope for updated research on the lifecycle of dairy products. There were several studies on the total energy inputs required for dairy processing, however there is an even larger research gap in this sector.

- There is a small body of research considering total energy inputs to other agricultural sectors in New Zealand. Further work, and the same kind of updating of previous findings, will allow for a better picture of energy usage in the agricultural industries of New Zealand to be established. The same methods used in this study should be easily transferable and comparable to other agricultural sectors, and an updated overview of New Zealand's total agricultural energy should be possible with data from the last ten years.

Finally, there are implications for the dairy industry. This study has identified that the primary drivers of energy use on farm come from the use of fertilisers and irrigation. Energy analysis offers a way to track the efficiency of this process that is consistent across all farms, and can be used to help guide the industry on a more sustainable path, by identifying the key factors of energy change. While there are other approaches to fertiliser use, such as nutrient budgeting and political trends towards nutrient limits in farming areas, there is little understanding yet of the implications for energy efficiency.

This thesis has shown the total energy inputs of the New Zealand dairy industry, and that despite large increases in those inputs, New Zealand still appears to have a strong competitive advantage in energy terms. This research can be used to validate that competitive advantage further.

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