Future-proofing New Zealand's Agricultural Food System

Energy-related risks and opportunities

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Introduction

New Zealand has an enviable reputation for the efficient production of comparatively large amounts of food for its population size. This reputation has been established over many years through ensuring our production systems have responded to global and national pressures, and optimising profitability without sacrificing quality.

In recent years the goalposts that determine 'quality' have been shifting, with changing consumer expectations in the global market for food systems to be more sustainable, and a growing global focus on energy use in and climate implications of food systems. Understanding the role of energy inputs in New Zealand's food production systems is a key part of adapting to these changing market expectations.

Previous literature exists on specific topics and case studies within the food value chain, but there is a lack of a high-level overview of quanta and trends in energy use throughout New Zealand's food system as a whole. There is also a lack of research examining the risks of current energy use patterns for the long term viability and profitability of agricultural exports. New and emerging opportunities for farmers and processors of farm products to get involved in energy generation and demand response are also under-explored.

This scoping paper has been undertaken as a desktop study to update and quantify energy use in New Zealand's food supply sectors. It investigates energy use in 'production' (on-farm production of food goods), processing (the processing of these goods into the form used by the customer), and post-processing (the transport and activity required to deliver and prepare the goods for consumption). Much of this data has been developed from re-analysis of government data sets, along with drawing from some prior studies. Unsurprisingly, there was a lack of detailed data in a number of areas, which has limited more fine-grained analysis.

We intend to use this document to engage stakeholders in agriculture and energy sectors, to help identify their perceptions of risks and opportunities, and identify areas in which future research would be supported.

If demand is evident and common themes can be identified across New Zealand's primary food production sectors, a research proposal will be developed to address two main issues:

- to investigate these themes in a collaborative and cost effective manner; and
- to translate the outcomes into practical and meaningful change that increases the resilience and profitability of our food production systems.

What kinds of energy are we interested in?

The energy going into any system can be categorised into two forms.

Direct energy inputs, which include electricity, diesel, biomass and other fuels used by farmers, processors and in transport.

Indirect energy inputs, which are embedded in the products and services used by famers, processors and in transport. An example is the energy required to manufacture fertilisers. The energy consumed in the production of goods and services is usually accounted for in the relevant sector (industrial, manufacturing, transport etc.), but should also be acknowledged as an indirect input if it represents a risk to current business models.

The big picture

The export value of all primary food products is **almost $30 billion NZD per annum, representing over half of our total export earnings** [1]. In addition, agriculture is the primary source of employment in many rural areas and its performance heavily influences the success of urban regions.

Direct energy demand in 2014 by the agricultural industry[1] was reported as 27PJ, 4.8% of national consumption [2]. But there is little benefit in considering the agricultural sector in isolation of the entire food value-chain. Only by including the direct and indirect energy that goes into processing and distributing agricultural produce do we get a true sense of the reliance of agricultural profitability on energy inputs. Studies which have attempted to do just this, suggest that closer to **30% of New Zealand's primary energy is associated with food production**. This is fairly evenly split between growing, processing, and distributing it to consumers (post-processing) [3]. Reasonable pricing and secure supply of this energy is therefore fundamental to our national prosperity.

Productivity is increasing in most New Zealand agricultural sectors, resulting in greater outputs per hectare. But, in order to achieve these productivity gains, the level of inputs into the agricultural system must also be increased. A balancing point will exist where increased inputs are no longer matched by equivalent increases in outputs; this is known as the law of diminishing returns, and an initial investigation indicates that we may already be at this point in several agricultural sectors[2] [4].
New Zealand's direct energy consumption has been increasing on average 1.5% pa from 1990-2014, while use in agriculture has increased by 2.3% pa and food processing by 3.7% pa over the same period (Fig. 1). While this is associated with increased production volumes and greater intensification (e.g. conversion of sheep farms to dairy farms), the New Zealand food supply sector should be aware of the potential risks and opportunities of this growing reliance on energy.

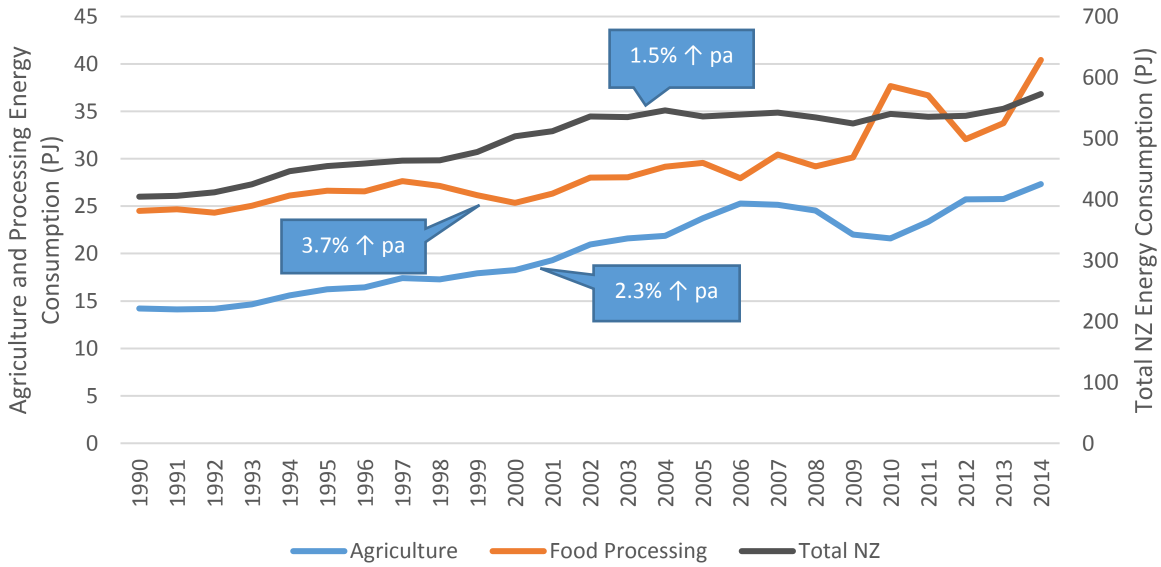

Figure 1. *New Zealand's direct energy consumption trends* [5].

While New Zealand's energy requirements are growing throughout the food supply system, we are also becoming more efficient at converting that energy into income. **The combined energy consumption of the agriculture and food processing industries has been growing at an average rate of 3.0% pa (Fig. 1), while the real export value of the food produced has increased by approximately 3.3% pa** [5-7]. The

[1] Excludes forestry and fishing. See Appendix A for complete ANZSIC06 breakdown of agricultural sector.
[2] See Appendix B for a summary of MPI modelled farm production intensities.

effect of any energy efficiency improvements are difficult to tease out from market fluctuations, which would also influence the export value of New Zealand's food products.

Current Energy Use in NZ Food Production

For the purpose of the current study, energy use in New Zealand's food production is divided into that used on-farm, during processing, and post-processing.

On-farm Energy Use

Total direct energy use on farms has doubled between 1990 and 2014 (Fig. 2). The sharp drop concurrent with the global financial crisis was mainly seen in a decrease in the consumption of diesel.

Direct energy

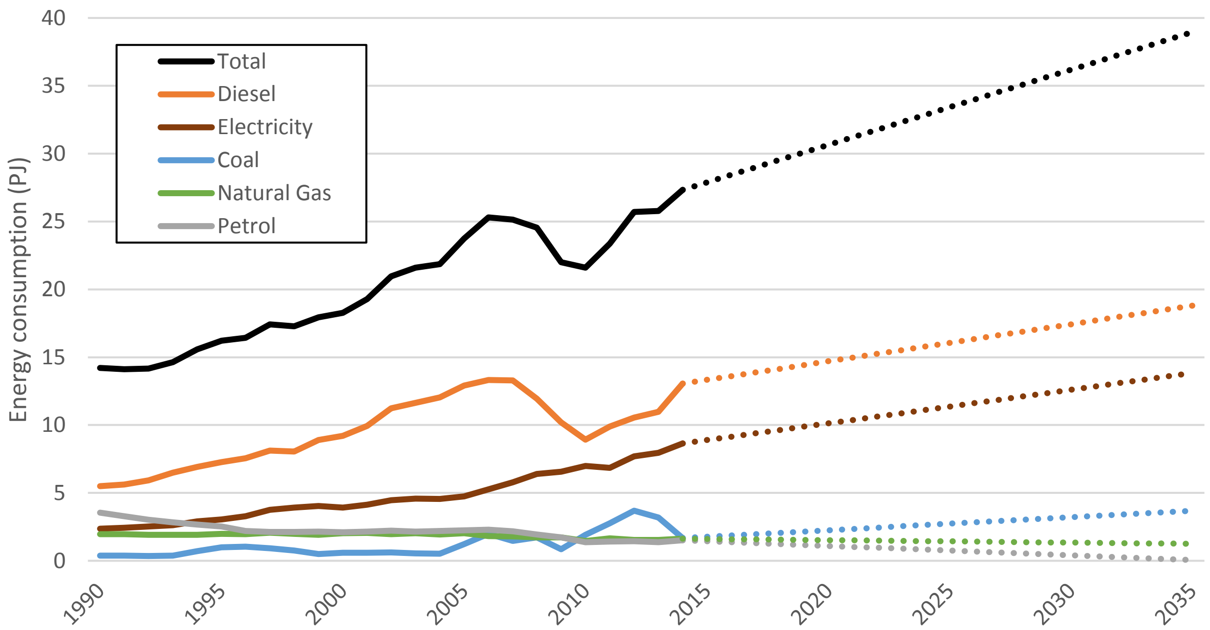

Figure 2. *Direct energy consumption in New Zealand agriculture by source from 1990 to 2014 with projections to 2035* [5]

The increase in direct energy consumption behind the farm gate is mainly driven by the **growing use of diesel and electricity**. In comparison, the use of petrol and natural gas have remained comparatively unchanged. Coal showed a brief spike in 2012 but then declined again [5].

In general, the main electricity uses on-farm are for water heating, refrigeration, and irrigation. Diesel and petrol are mainly used for farm machinery and vehicles [8]. The sheep-beef and dairy sectors are by far the largest consumers of direct energy inputs on-farm (Fig. 3). This is consistent with their total size representing 81% of New Zealand's agricultural land area [9].

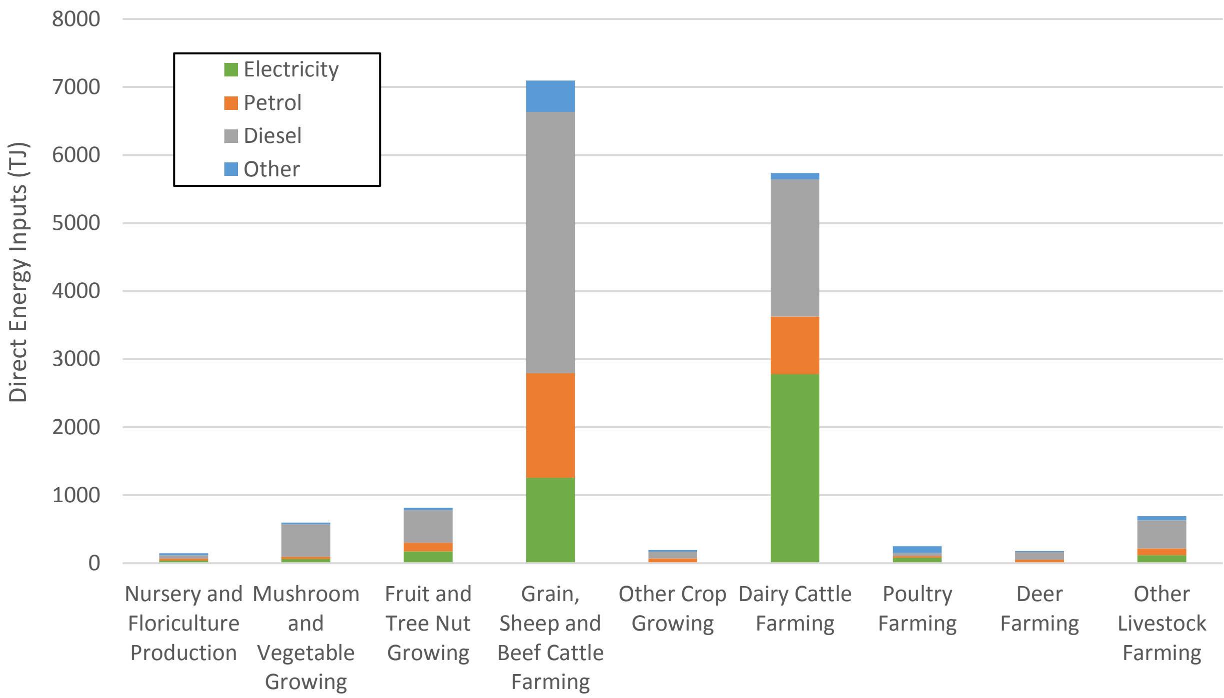

Figure 3. *Direct energy inputs by agricultural sector[3] in 2011 (ANZSIC06 level 3)* [10]

Indirect energy

Indirect energy inputs are difficult to quantify. Most studies that have attempted this are case studies at the farm level or life-cycle assessments. This has created a range of figures dependent on the location and farm type, which are not possible to extrapolate to the entire agricultural sector. Table 1 provides a brief summary of some of the previous work done in this area. Several other studies focus primarily on the greenhouse gas emissions of these energy profiles so are not directly comparable to the data in table 1 [11]. Energy profiles are often used to visualise the total energy requirements of a system, by partitioning it by source (electricity, fuel etc.).

Table 1. Summary of several New Zealand agricultural energy use profiles as a percentage of the total energy inputs into the particular agricultural system.

Farm Type	Direct Inputs		Indirect Inputs			Study Date
	Fuel	Electricity	Fertilisers	Other Indirect	Capital	
Dairy (non-irrigated)	21%	20%	38%	8%	13%	2001 [12]
Dairy (irrigated)	13%	40%	34%	6%	7%	2001 [12]
Arable	14%	45%	28%	4%	9%	2004 [13]
Potato	32%	3%	42%	14%	9%	2004 [13]
Onion	40%	1%	25%	24%	9%	2004 [13]

On the basis of this work it appears that **indirect inputs could be in the order of 50-60% of total farm energy use**. Further work is required to update these findings and to establish more generalizable data.

[3] See Appendix A for complete ANZSIC06 breakdown of agricultural sector.

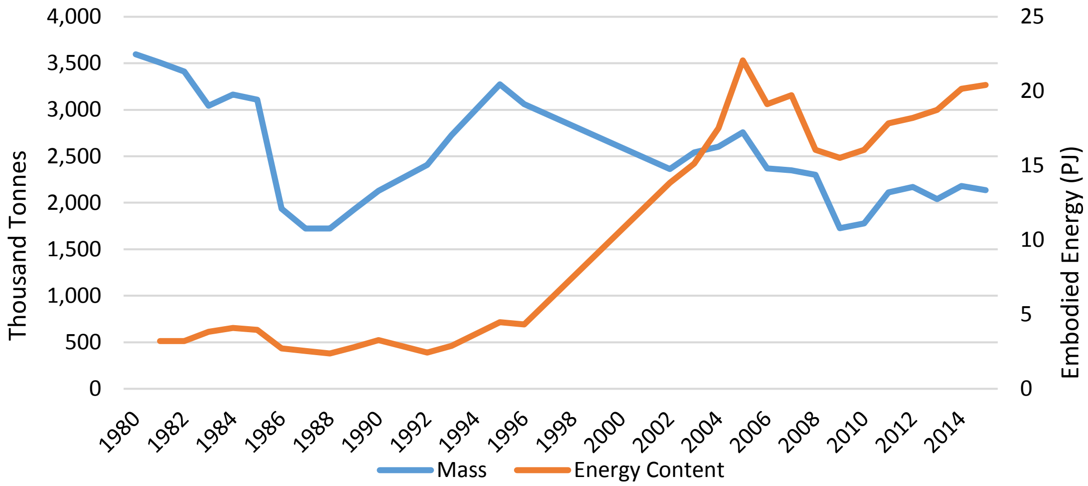

Figure 4. *Mass and embodied energy of applied fertilisers (1980 - 2015)* [14, 15]

A major portion of indirect energy is embedded in fertilisers. Recent trends see a shift from traditional bulk fertiliser applications to lower volumes of more concentrated fertilisers. This is shown in figure 4 by the **40% decline in the mass of fertilisers applied throughout New Zealand, but a 540% increase in their embodied energy**. The increase in the use of urea (nitrogen based fertiliser) is the main driver as it is extremely energy intensive to produce. Every kilogram of urea produced in New Zealand requires 52MJ of energy [15], or approximately 0.7kg of natural gas [12]. Its rate of application has increased ten-fold in New Zealand since the early 1990's [14].

Relationship between energy, land area, and income

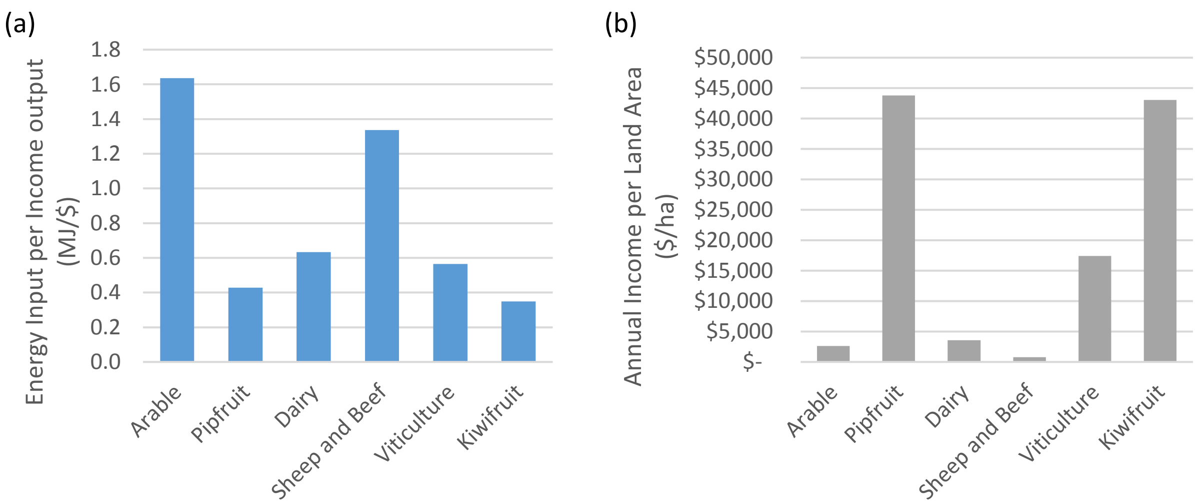

Figure 5. *(a) Total energy intensity per dollar of income and (b) Income per land area by sector* [9, 16-24]

Figures 5a and 5b show average direct and indirect energy and income intensities of various agricultural sectors at the farm gate. The covered crop sectors have been removed as they cannot be compared with the traditionally lower intensity outdoor agricultural sectors. These figures have been compiled from 10 different sources as a standardised measure of land use performance for entire sectors does not exist in one location. Because of the conversions required to create a single unit of performance, as well as the different accounting measures of each sector, and the required extrapolations, these results should be taken as indicative only. Figures 5a and 5b still reveal some interesting comparisons, although further work will be needed to validate any conclusions.

The figures indicate that the ability to convert input energy into financial income varies five-fold across the primary food production sectors. Kiwifruit is the best, it can make a dollar with just over 0.3MJ. The arable and sheep-beef sectors are the worst, they make a dollar with around 1.6 and 1.3 MJ respectively. Interestingly, comparing the two animal-based sectors, dairy is just over twice as efficient as sheep-beef in this regard. The ability to convert land area into income varies by far more. There is more than 20-fold difference between the sheep-beef sector (~$2,000/ha), and the pipfruit and kiwifruit (~$43,000/ha) sectors. However, higher land area incomes also require much greater levels of inputs to maintain those incomes. Figure 6 shows the average expenditure profiles for each of these sectors. This reveals that **direct energy inputs (electricity and fuel) make up a comparatively small proportion of total expenses, ranging from 4-9%[4] (apart from on-site packing of pipfruit).**

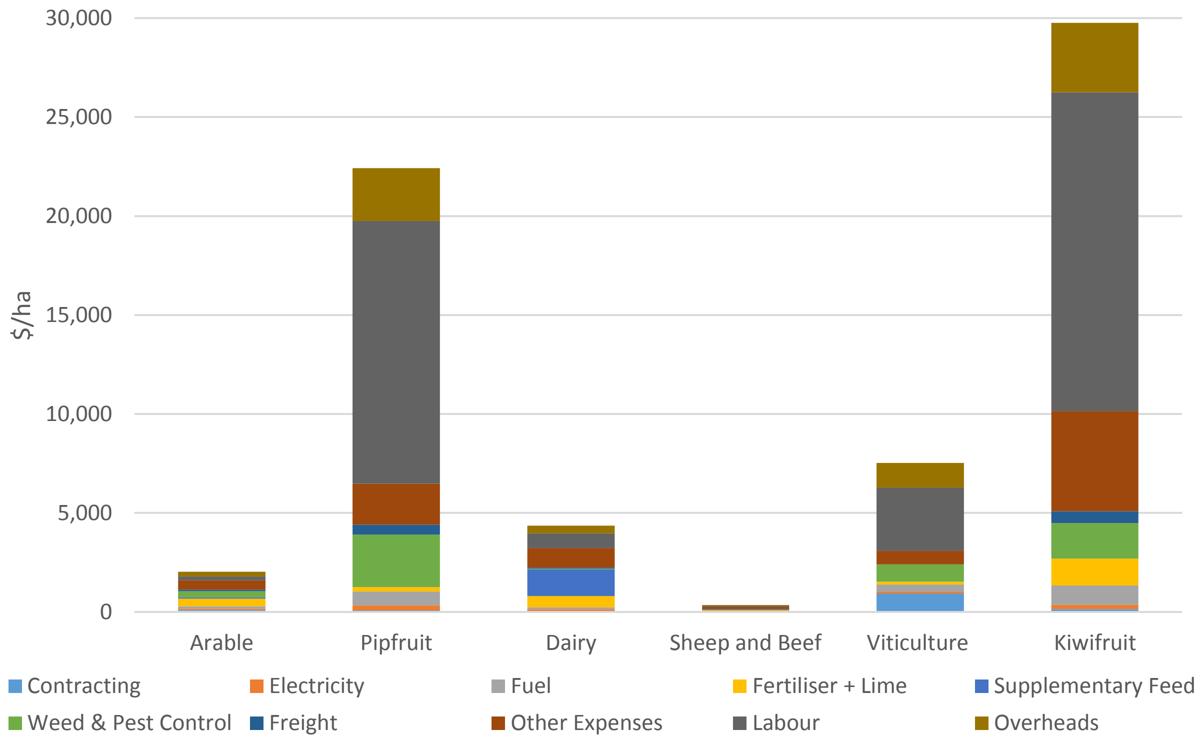

Figure 6. *Average farm expense profiles for main New Zealand agricultural industries* [25-30]

The energy intensities and the income potential of land appears to be consistent with trends observed throughout New Zealand, where traditional sheep-beef farms have been converted to dairy, and several Hawkes Bay dairy farms have converted to vineyards. This can only be done where the land and conditions are appropriate, but each conversion represents a step towards a lower energy income intensity and a higher income per land area.

Processing Energy Use

Direct energy

Energy used to convert farm outputs into products that will be purchased by NZ or international consumers makes up about one third of the total energy used in the food chain [3].

Not all food processing sectors are directly comparable, however, as their energy demands depend on the services offered to both the farmers and the consumers. For example, some food processors own their own vehicles to collect products from farms and/or deliver them to their customers or distribution

[4] Detailed expenditure breakdowns of each agricultural sector are presented in Appendix B

points, so the energy used for this transportation will be listed under the food processor. Companies that do not offer this service will require a third party to link the producer and processor, so the energy used for this will be listed under New Zealand's transportation sector. **The quantum of energy used for transport of agricultural produce is therefore unknown and would require future bottom-up studies to quantify its importance.**

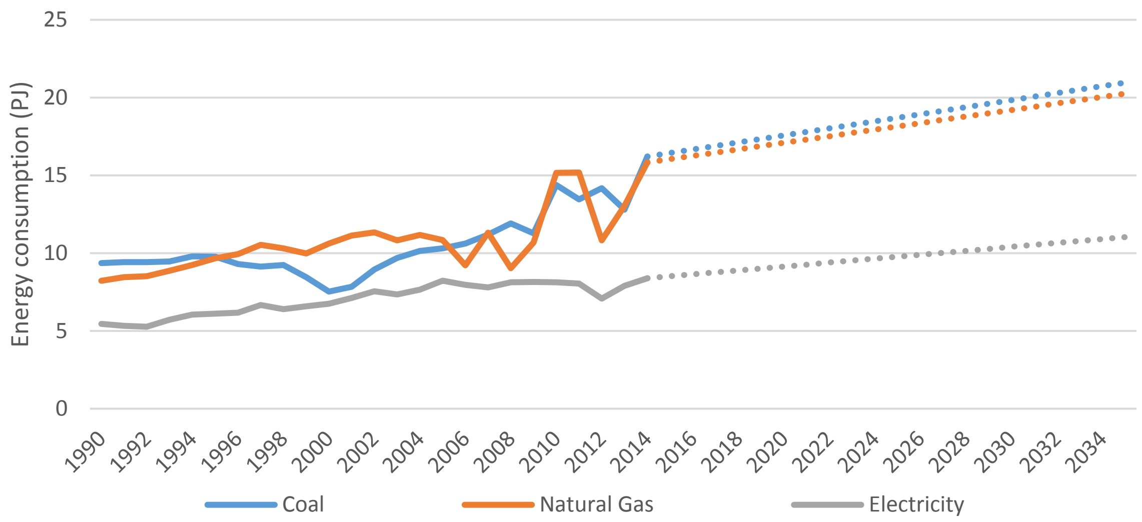

Figure 7. *Extrapolated food processing*[5] *energy consumption by source* [5]

The food processing industries consume around 10% of New Zealand's primary energy, and the dairy and meat processing sectors make up over 70% of this (Fig. 8). This is similar to the amount of direct and indirect energy inputs of all New Zealand farms. **The cost associated with this direct energy is a comparatively minor component of their budgets, at 5-15% of total expenses. The majority of this energy use is for process heat, and is largely supplied by fossil fuels** [3].

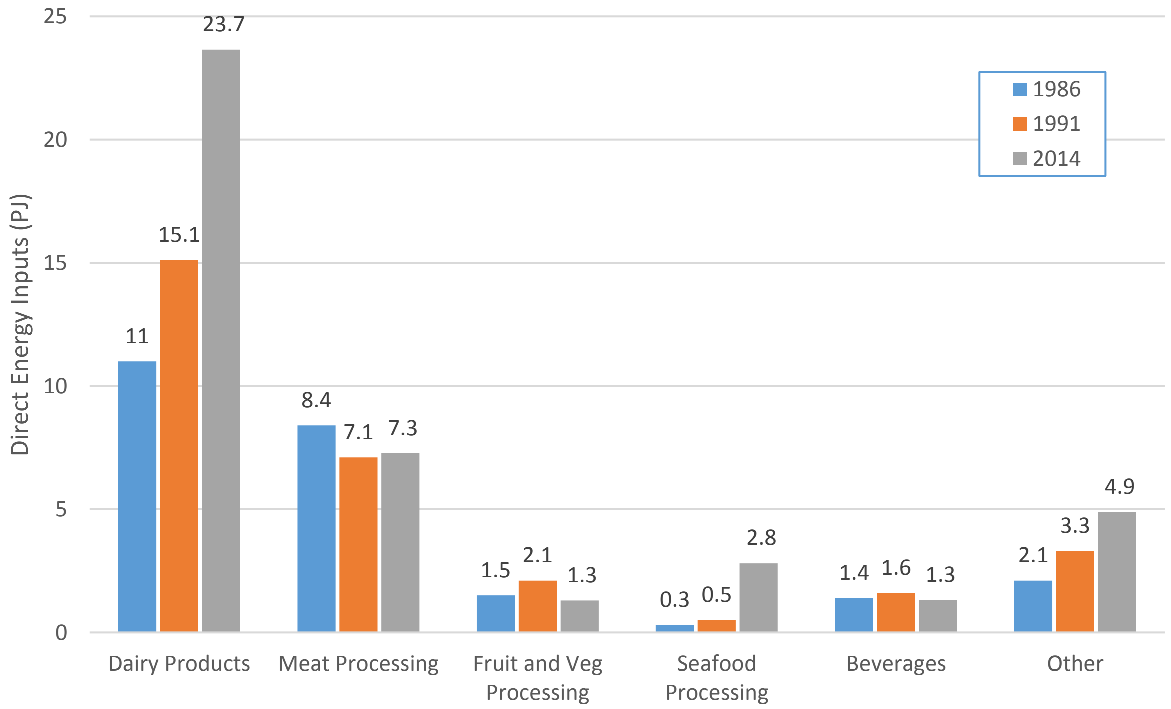

Figure 8. *Direct energy used in food processing sectors* [3, 31]

[5] See Appendix D for complete ANZSIC06 breakdown of food processing sector.

In 2014, direct energy consumption by the dairy processing sector was three-fold larger than for the meat processing sector and about seven-fold larger than the next individual processor which is seafood.

In the dairy processing sector, energy use has slightly more than doubled to 23.7 PJ in the past couple of decades. In contrast, consumption by the meat processing sector has declined slightly to 7.3 PJ.

An audit of 10 meat and fish processing plants showed an average energy portfolio consisting of 42% electricity, 37% coal and 22% natural gas. The majority of the electricity is used for refrigeration, while coal and gas are used to generate process heat [32].

Indirect energy

Indirect energy consumption in the food processing sector is mainly apparent in three forms.

- Energy embedded in the products received for processing; this has already been accounted for in the on-farm section so does not need to be included as an additional input in the food processors' energy balance.
- Packaging of products for both ease of handling and to enhance its lifespan. Various requirements will dictate how and why different products are packaged, but this can be a major contribution to the overall energy consumed in the food system. In the New Zealand wine industry, it is estimated that over one third of the total energy used in the lifecycle of a bottle of wine is related to the production of the bottle itself [33]. Altering the way a product is packaged will affect the amount of energy embedded in the packaging, but may also result in implications for distribution and waste creation.
- Capital and maintenance inputs, which have not been included in the current study, as they are very specific to individual locations and can therefore not easily be extrapolated to cover an entire industry.

Post-processing Energy Use

Distribution accounts for approximately 18% of the energy used in New Zealand's primary food production. This is much higher than most other developed countries because NZ must transport its export goods comparatively long distances [3]. Export of New Zealand primary food products consumed around 16PJ of Heavy Fuel Oil in 2007, which accounts for approximately 25% of the energy used to export all New Zealand products [34]. Around 70% of these food exports also require some form of climate control during distribution, which can add an additional 20% to the total amount of direct energy consumed during transportation [35].

Indirect energy associated with the creation and maintenance of transportation systems is another significant factor, but not investigated in this study. However, international studies suggest that building and maintaining roading infrastructure could be equivalent to around 10% of all the energy used by the traffic on those roads [36]. In New Zealand that would be equivalent to approximately 20PJ, or 3.5% of primary energy consumption [5]. This example is used to illustrate the importance of indirect inputs into our transportation system, which is vital to current food production systems in New Zealand.

Waste streams exist throughout each stage of the food supply system and they all represent some form of embodied energy which was not utilised. In developed nations, the creation of food waste is more heavily focused towards the consumer end of the food chain, whereas developing countries tend to create larger amounts of waste during the pre-distribution phases of food supply[37]. Waste from any system represents an unused potential in the form of the embodied energy in the discarded product. This can take many forms and reducing waste can affect the overall energy balance of a system by decreasing the need to invest energy in produce that is not used. A report on food waste in the UK suggests that around one third of all food purchased is not consumed [38]. Countries within North America and Oceania are some of the largest contributors to food waste globally, and throughout the food chain, up to 60% of some food types are wasted [37].

National Energy Trends

Having examined how energy is used in primary food production, we now look at overall trends in energy use in New Zealand.

Fossil Fuels

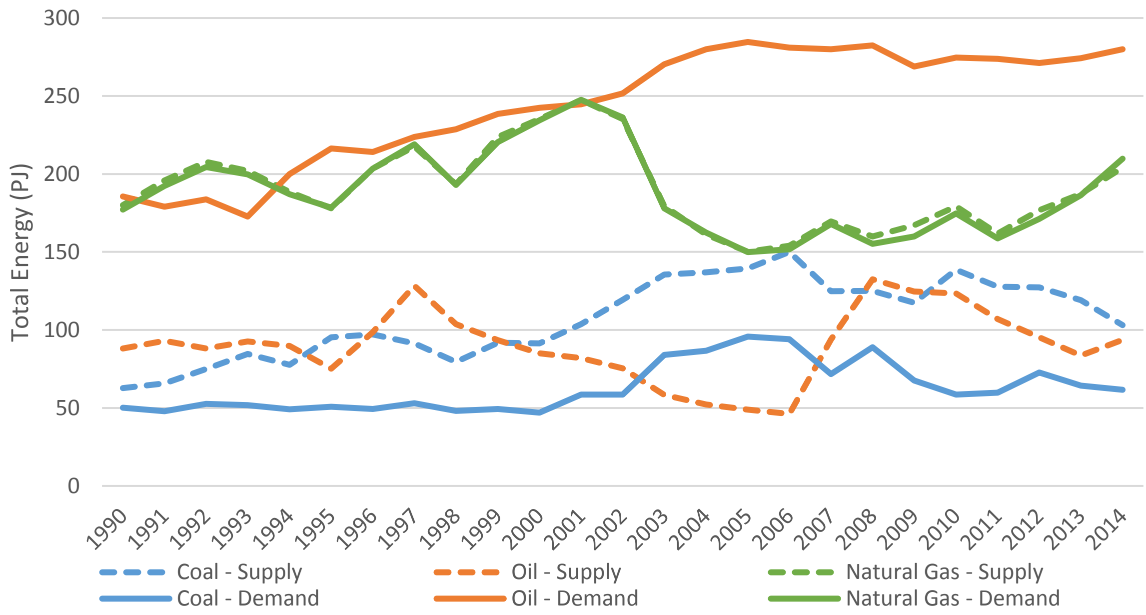

Figure 9. *New Zealand's domestic supply and demand of fossil fuels* [5]

Figure 9 compares supply and demand of fossil fuels for New Zealand as a whole. Natural gas production is matched to demand as all supplies are used domestically. We extract around 100 PJ of coal per year, with half of that used domestically and half exported. The major disparity is between domestic oil production and consumption; production has fluctuated around 100PJ over the long term, while consumption has continued to increase, which exposes our reliance on imported oil.

Remaining reserves of New Zealand oil and condensate are estimated at 682 PJ, or 22% of what was ultimately recoverable. In 2014, indigenous production was 94 PJ, of which 87 PJ was exported. If all oil was used domestically, this would only meet one third of the domestic demand [39].

Electricity

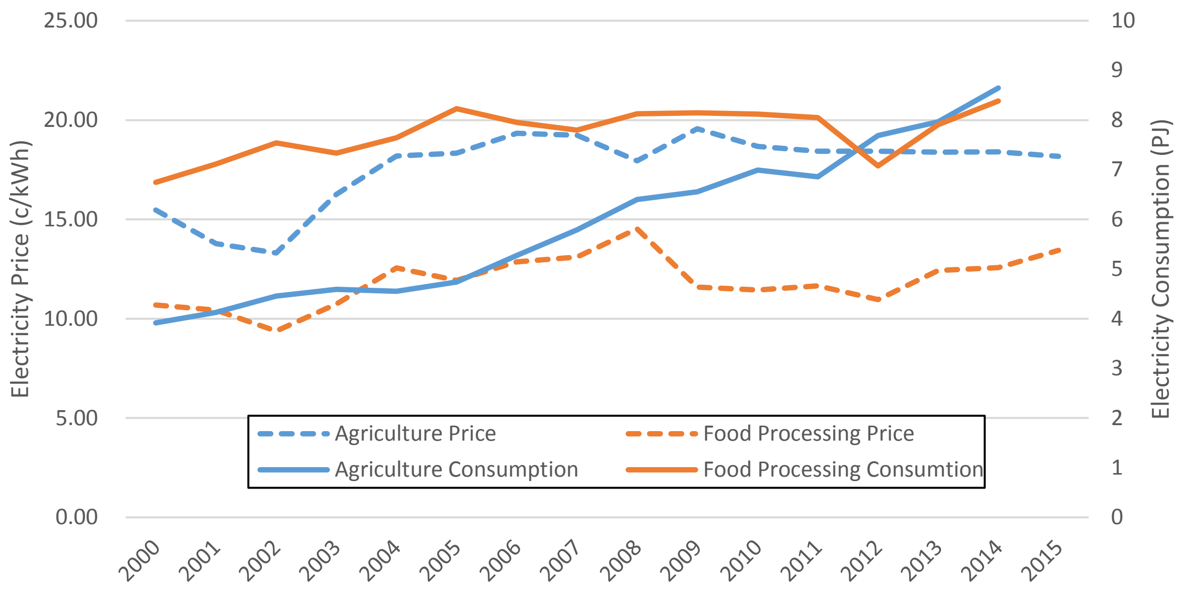

Figure 10. *Real electricity costs and consumption for agriculture and food processing sectors* [5, 40]

Figure 10 shows that electricity prices for commercial (agriculture) and industrial (food processing) customers over the past 15 years have followed a broadly similar trend. The long term trend is a small increase, equivalent to approximately 1.5% per annum in real terms, although this appears to have stabilised since around 2009. The use of electricity in these sectors shows markedly different trends. **Electricity used to process food products increased until 2005, but has remained relatively constant for the last 10 years. Electricity used on farms however, is increasing at a fairly consistent rate, equivalent to about 5% per annum, and has more than doubled over the past 15 years. These increases in agricultural electricity use correlate well with allocated irrigation water consumption rates, which have been increasing at an average of 3% pa from 1999 to 2010** [41]. **As of 2012, more electricity was used on farms than in the food processing industries** [5].

Quantifying Exposure

One aspect of risk is the security of supply and price volatility of fossil fuels, particularly oil. **While oil prices are currently relatively low they have fluctuated significantly over the past 15 years, with cost implications for oil-dependent sectors.** There is also international pressure to decarbonise the global economy to help mitigate the effects of climate change. The United Nations Framework Convention on Climate Change (UNFCCC) have agreed that warming should be limited to below 2°C to avoid dangerous climate change, of which we are already halfway there [42]. Because of the lag in climatic systems, two-thirds of the established emissions budget has already been used if warming is to be limited to less than 2°C [42]. Additionally, in 2015, 197 countries signed up to the Paris Agreement, which aims is to keep global temperature rises this century to well below 2°C above pre-industrial levels, and to pursue efforts to limit the temperature increase even further to 1.5°C [43]. For New Zealand to achieve their part of this global agreement, they have pledged to reduce greenhouse gas emissions by 30% from 2005 levels by 2030, which is equivalent to a 38% reduction from current emissions levels over the next 13 years [44]. Mitigation options are available in all major sectors and will require substantial emissions reductions over the next few decades and to near zero net emissions by the second half of the century [45].

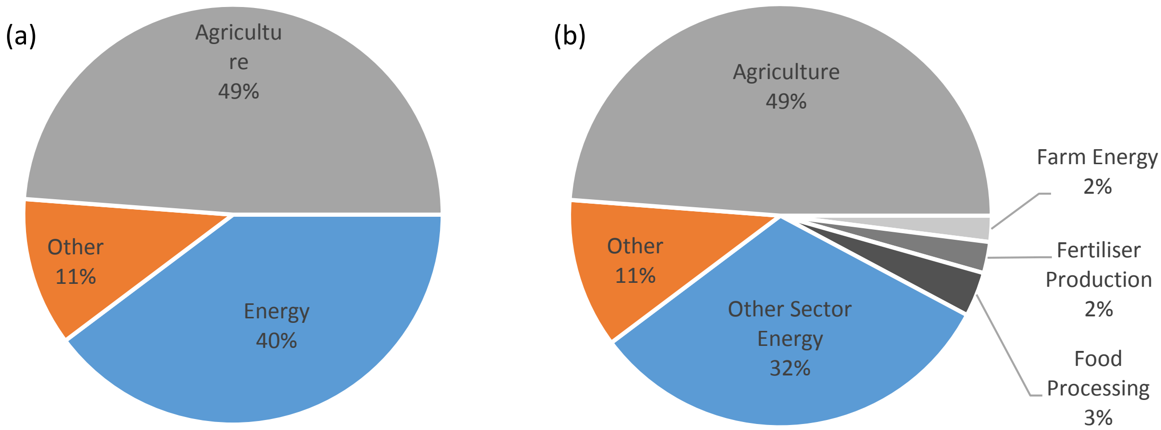

Figure 11. *(a) New Zealand's accountable gross emissions by sector and (b) those assosicated with agriculture (grey shades)* [5, 46]

Emissions from animals and land use (mainly methane and nitrous oxide) make agriculture by far the largest contributor at 49% of all of New Zealand's gross greenhouse gas emissions (Fig. 11a) [47]. **However, the energy-related emissions from the sector are less well known.**

Our analysis (Fig. 11b) indicates that an additional 4% (3.5 million tonnes CO_2 equivalent) of national emissions are due to the direct use of energy on farms, and energy embedded in fertilisers (other indirect energy has not been included due to insufficient data). Emissions relating to the food processing industry were around 2.6% (2.7 $MtCO_2$-e in 2014) of New Zealand's total GHG emissions [5, 12, 48-50]. As noted, some transport energy use is not captured in these figures. **This brings the total energy-related emissions from the agricultural sector to around 7%. The total of all agricultural related activity thus produces at least 56% of New Zealand's GHG emissions**.

Estimates from Fitzgerald et al. [34] **suggest that international shipping of New Zealand's food products could add an additional 2% (1.2 $MtCO_2$-e) of emissions to our national total.** However, any greenhouse gas emissions from international transport are not currently included in national emission profiles.

Building Resilience

The dependence of our primary food production systems on energy, and in particular on fossil fuels, raises a number of potential risks which we outline below. We also outline a number of opportunities for the rural sector arising out of global trends and New Zealand's distinctive characteristics.

Risks

Because of the high reliance on imported energy in intensive food production systems, many developed countries like New Zealand will face the issues of vulnerability from dependence of fossil fuels at roughly the same time. It is therefore in our best interests to have a plan in advance for how we will contend with those energy issues and keep New Zealand at the forefront of global food production system development.

The trends presented in figures 1-10 indicate ongoing increases in energy use throughout New Zealand's food producing sectors. This is unsustainable and represents a real risk for all New Zealand food supply sectors.

On Farm Energy Use:

- Significant and ongoing increases in electricity and diesel use on farms (Fig. 2). If this is rising faster than value of products at the farm gate, it has implications for profitability. Particularly concerning is the potential for price spikes in oil.
- A large proportion of energy inputs to a farm are indirect, and are predominately linked to fertiliser application (table 1). Increases in the price of energy intensive inputs (or their related carbon cost), if combined with comparatively little change in farm-gate returns, will directly impact on profitability.
- 85% of all energy used in farming is non-renewable - implications for increased farm costs in future due to carbon pricing along, with vulnerability to oil price fluctuations [12]. (Although this figure is from a 2001 study, preliminary assessments of current energy profiles suggest this is still relatively accurate [5].)
- Irrigation growth is resulting in greatly increased electricity use, with case studies suggesting an approximate trebling of electricity consumption after irrigation installation [12]. Risks for farmers from increasing proportion of electricity costs; reliability of electricity supplies in some instances; problems for some electricity distribution companies in managing demand peaks [51].

Processing Energy Use:

- Most process heat comes from the use of coal and gas (Fig. 7). This may have repercussions for (a) the vulnerability to carbon pricing and (b) the vulnerability to global markets sensitised to carbon content of foods. Fuel switching is technically possible but will require suitable market and/or policy conditions to encourage it [3, 52].
- Packaging can account for up to a third of the energy requirements of a product throughout its life cycle, but can also affect the life span, quality, and accessibility of products delivered to markets [33]. Any changes to product packaging to improve energy performance will require a holistic view to include all of these factors.

Distribution Energy Use:

- Almost exclusively driven by fossil fuels, primarily diesel and heavy fuel oils for shipping. Potential for some domestic load to be shifted to other forms of transport or fuels, but this will require favourable market and/or political incentives [52]. Due to New Zealand's geographic location, few opportunities exist to alter the means by which products are delivered to international markets [34]. The lack of ability to influence this area means that other sectors of the food chain may have to compensate in order for the entire industry to remain competitive.

System Wide:

- Waste streams exist throughout every stage of the food supply system. Discarded products and resources represent unused potential energy, and will subsequently require additional energy to be added to the system to make up for these losses.

Market Access Barriers:

- As an export dependent country that relies on accessing high value food markets internationally, NZ food exporters have been highly sensitised to an emerging market access environment in which increasingly stringent quality requirements are being placed on supply chains and food products. Since the mid-1990s, the number of audit and assurance schemes in markets like the UK/EU have escalated with now over 350 specific schemes being identifiable, and acting as a barrier to market access for NZ food exports [53].
- In 2007, the 'food miles' crisis indicated the degree to which an energy-related market access barrier might emerge and form an unexpected and economically punitive challenge to food exporters.

- In 2018, new legislation comes into effect which will require milk to be chilled quicker, and to a lower temperature than previously required by dairy farmers. This will align New Zealand milk production with international standards in an attempt to remove barriers to foreign markets, and will have direct repercussions for on-farm energy use [54].
- Agriculture is responsible for 49% of New Zealand's greenhouse gas emissions from methane and NO_2, plus an additional 7% from fossil fuels used by farms and food processors (Fig. 11). Reducing these emissions, as required by international agreements, will increase the pressure on New Zealand's food supply sectors if they are to maintain market access.
    - Discrepancies will arise here due to the methods used to account for New Zealand's greenhouse gas emissions compared to those actually related to the functioning of our economy. For example importing/exporting fertiliser or supplementary feed will not alter our emissions profile, but the import or export of coal will. Also, international transport is not currently accounted for under international agreements such as the Kyoto protocol or the Paris Agreement [34]. All of these factors could result in additional greenhouse gas emissions being attributed to New Zealand's food production.

Areas of greatest vulnerability:

- Due to its reliance on fossil fuel inputs, New Zealand's primary food production systems appear vulnerable to (a) oil price variability, (b) carbon prices, and (c) potential for new market access barriers, and changing consumer preference for clean, 'carbon free' products.
- The biggest proportion of fossil energy in the sector is consumed in process heat (coal and gas) and fertiliser production (gas).
- Due to the high reliance of the entire food chain on energy (particularly fossil fuels), any disturbance to the cost or security of supply could affect the entire sector.
- Debt becomes more difficult to manage with fluctuating energy prices.
- The consumption of transport fuels has not been able to be fully quantified, but is likely to be significant as well.
- On-farm electricity use has more than doubled in the past 15 years, primarily driven by the growth in irrigation, but also large amounts of usage for water heating and milk cooling.

Opportunities

There is a significant opportunity and need for New Zealand's entire food industry to move towards a lower energy intensity and renewable based production system. This will offer improved resilience to price fluctuations and also respond to consumer/market demands towards more sustainable and environmentally friendly methods of food production.

On Farm:

- Load shifting: Changing when electricity is used to take advantage of various financial incentives offered by power companies or aggregators. This does not change the total amount of energy consumed, but just when it is consumed. Potentially large financial savings are associated with reducing the peak demands on local and national electricity networks and generators by moving energy intensive farming operations outside of peak times. E.g. irrigation, water heating, refrigeration, effluent and water pumping etc. Current offerings include:
    - Tariff Based Incentives: Actively changing energy consuming behaviours to take advantage of variable pricing structures such as 'time of use' or 'day/night' tariffs.
    - Ripple control: Electricity retailers offer reduced tariffs to customers that allow certain loads to be remotely controlled (such as water heating).
    - Curtailable Load: Users are directly requested to reduce load during times of high demand in exchange for financial reward.

  - Interruptible load: Financial rewards offered for loads that can be instantly shed during low frequency events in the grid to prevent network wide failures/power cuts. New Zealand's total Interruptible load was worth $66 million in 2009 [51].

- Increase efficiency, reduce demand:
  - Opportunities for precision farming through increased monitoring and automation. The main areas for improvement relate to irrigation and fertiliser application. This will result in reduced energy use, improved plant growth, less water use, and reduced nutrient run off.
  - Energy efficiency improvements through plant upgrades. EECA estimates that around $42 million per year of electricity could be saved in New Zealand dairy sheds alone [55].
  - Partial on farm processing to reduce the amount of waste transported from farm to processing plant. Operational units have shown to be able to halve transportation costs of milk from farm to processor in exchange for an additional electrical load at the dairy shed [3]. The value of this would therefore be a function of transportation cost savings vs additional electrical expense.

- Switching to renewable fuels. For example, electric vehicles for on-farm use; use of farm-produced biofuels for heating and transport.

- Farm energy production as another 'crop' for use on-farm or for sale, e.g.
  - Photovoltaics: electricity generation for on-farm use or selling into the national grid. Approximately 180kWh of electricity can be generated per square metre covered in solar panels every year [56]. In 2016 this equated to around $50/m^2/year if used to offset electricity normally purchased from the grid [57], and PV prices are rapidly reducing (halving every 13 months since 2008). Large scale PV would have to sell electricity into the national grid at wholesale rates, so revenue would depend on the time of production and the spot market prices.
  - Biogas: convert waste water and effluent streams into electricity and/or heat for direct use. Also reduces effluent odour and is better for soils than direct application. Applications would vary by site, but one North Island piggery has replaced approximately 16kW of heating load, which represents electricity savings of around $23,500 per annum [58].
  - Micro-hydro/wind: electricity generation for direct use or sale into the national grid. The same principals as photovoltaics apply, and the amount of displaceable electrical load or potential revenue would depend on the resource (water/wind) available.
  - Micro-grids: creating a network of local infrastructure to share resources between neighbouring farms. This may be in the form of electricity, water, heat or waste water. Micro grids can create new revenues form otherwise unutilised resources by pooling assets and directly linking producers with consumers. There are many successful examples of this throughout Europe with district heating schemes.
  - On-farm storage of energy. Electricity that is surplus to requirements can be stored in batteries, or in heating or cooling water. Battery technologies are rapidly improving and reducing in price.

Processing:

- Switching from fossil fuels towards renewables for process heat. This is technically possible but may require further R&D for NZ circumstances and suitable policy/market environment to encourage [59].
- The use of a biodiesel blend, e.g. as in some of Fonterra's milk tankers [60]. Financial benefits are currently negligible as biofuels are only becoming available as they can begin to compete with the increasing price of existing fuels, whether that is due to traditional price increases or the introduction of greenhouse gas emissions charges.

- Different packaging methods can reduce the indirect energy embodied in the packaging materials themselves, but also has the possibility to increase shelf life and improve quality (subsequently reducing waste), and to reduce transportation costs.

Distribution:

- Although primarily fossil fuel based, some potential to switch to biofuels exists, although this will require favourable market and/or policy conditions [60].

General:

- Reduce exposure of agriculture to risks and also add value to the entire sector through the marketing of products that are more able to be verified and authenticated as being sustainably produced.
- Improve productivity and reduce costs in the long term.
- Address waste streams throughout the food supply system to reduce energy demands and use existing resources more efficiently.
- Many actions have co-benefits such as improved water and air quality, reduced environmental pressures, positive health benefits. Finding solutions with co-benefits can help strengthen the basis for action, compared to approaching these issues separately [61].

Summary: In the immediate term there are real opportunities in better management of electricity, especially with irrigation, which is a central tool in supporting agricultural intensification. Supplementing on-farm income with energy generation is already being undertaken by some farmers. There are encouraging possibilities in processing around heating, cooling, and drying with alternative fuels. Transport fuels are a challenge, but there is ongoing work towards implementing biofuels in certain sectors, and electrification will suit some niches.

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Appendix A

Australian and New Zealand Standard Industrial Classification (ANZSIC) 2006 agriculture breakdown [62]

Level 1	Level 2	Level 3	Level 4	
A	Agriculture, Forestry and Fishing			
	A01	Agriculture		
		A011	Nursery and Floriculture Production	
			A011100	Nursery Production (Under Cover)
			A011200	Nursery Production (Outdoors)
			A011300	Turf Growing
			A011400	Floriculture Production (Under Cover)
			A011500	Floriculture Production (Outdoors)
		A012	Mushroom and Vegetable Growing	
			A012100	Mushroom Growing
			A012200	Vegetable Growing (Under Cover)
			A012300	Vegetable Growing (Outdoors)
		A013	Fruit and Tree Nut Growing	
			A013100	Grape Growing
			A013200	Kiwifruit Growing
			A013300	Berry Fruit Growing
			A013400	Apple and Pear Growing
			A013500	Stone Fruit Growing
			A013600	Citrus Fruit Growing
			A013700	Olive Growing
			A013900	Other Fruit and Tree Nut Growing
		A014	Grain, Sheep and Beef Cattle Farming	
			A014100	Sheep Farming (Specialised)
			A014200	Beef Cattle Farming (Specialised)
			A014300	Beef Cattle Feedlots (Specialised)
			A014400	Sheep-Beef Cattle Farming
			A014500	Grain-Sheep and Grain-Beef Cattle Farming
			A014600	Rice Growing
			A014900	Other Grain Growing
		A015	Other Crop Growing	
			A015100	Sugar Cane Growing
			A015200	Cotton Growing
			A015900	Other Crop Growing n.e.c.
		A016	Dairy Cattle Farming	
			A016000	Dairy Cattle Farming
		A017	Poultry Farming	
			A017100	Poultry Farming (Meat)
			A017200	Poultry Farming (Eggs)
		A018	Deer Farming	
			A018000	Deer Farming
		A019	Other Livestock Farming	
			A019100	Horse Farming
			A019200	Pig Farming
			A019300	Beekeeping
			A019900	Other Livestock Farming n.e.c.

Appendix B

Annual productivity changes by agricultural sector. Averaged from variations over 5 years (seasons ending in 2009-2013) presented in relevant Ministry for Primary Industries monitoring reports.

Annual Improvements	Productivity intensity (units/ha)	Net income ($/ha)	Net expenses ($/ha)
Dairy (kg MS)[1]	2%	6%	6%
Sheep & Beef (SU)[2]	3%	12%	10%
Kiwifruit (trays)[3]	-2%	4%	2%
Marlborough Grapes (t)[4]	2%	-1%	-6%
Hawke's Bay Grapes (t)[4]	-2%	1%	0%
Hawke's Bay Pipfruit (TCE)[5]	3%	2%	3%
Nelson Pipfruit (TCE)[5]	1%	-1%	1%

[1]Kilograms of Milk Solids [27]
[2]Stock unit – Standardised method to compare different stock in terms of ewe equivalent [28]
[3]A tray contains approximately 3.6 kilograms of kiwifruit. [30]
[4]Tonnes [29]
[5]Tray carton equivalent is a measure of apple and pear weight (18.6 kg packed weight = 18.0 kg sale weight) [26]

Note that in most cases, expenses have increased at a greater rate than the productivity intensity. This indicates that a greater amount of inputs are required to get a smaller return on productivity improvements. Vineyards in Marlborough are the exception to this, which have managed to increase production per hectare while at the same time decrease expenses. Caution must be taken when comparing monetary values however, as market variations will have more of an impact on expenses/income that the physical amount of inputs/outputs. Further work is therefore required in this area to tease out the energy intensity of both the system inputs and production to allow a fair comparison.

Appendix C

Expenditure profiles for main New Zealand agricultural sectors

Expenditure by farm type	Arable [25]	Pipfruit [26]	Dairy [27]	Sheep and Beef [28]	Viticulture [29]	Kiwifruit [30]
Contracting	5%	0%	0%	0%	12%	0%
Electricity	3%	1%	3%	2%	1%	1%
Fuel	6%	3%	2%	5%	5%	3%
Fertiliser + Lime	19%	1%	13%	22%	2%	5%
Supplementary Feed	3%	0%	31%	7%	0%	0%
Weed & Pest Control	15%	12%	1%	3%	12%	6%
Freight	4%	2%	1%	2%	0%	2%
Other Expenses	23%	9%	23%	34%	9%	17%
Labour	9%	59%	17%	11%	43%	54%
Overheads	12%	12%	9%	15%	16%	12%
Total Expenses ($/ha)	$2,035	$22,416	$4,356	$348	$7,532	$29,764

Appendix D

Australian and New Zealand Standard Industrial Classification (ANZSIC) 2006 food processing breakdown [62]

Level 1	Level 2	Level 3	Level 4	
C	Manufacturing			
	C11	Food Product Manufacturing		
		C111	Meat and Meat Product Manufacturing	
			C111100	Meat Processing
			C111200	Poultry Processing
			C111300	Cured Meat and Small goods Manufacturing
		C112	Seafood Processing	
			C112000	Seafood Processing
		C113	Dairy Product Manufacturing	
			C113100	Milk and Cream Processing
			C113200	Ice Cream Manufacturing
			C113300	Cheese and Other Dairy Product Manufacturing
		C114	Fruit and Vegetable Processing	
			C114000	Fruit and Vegetable Processing
		C115	Oil and Fat Manufacturing	
			C115000	Oil and Fat Manufacturing
		C116	Grain Mill and Cereal Product Manufacturing	
			C116100	Grain Mill Product Manufacturing
			C116200	Cereal, Pasta and Baking Mix Manufacturing
		C117	Bakery Product Manufacturing	
			C117100	Bread Manufacturing (Factory-based)
			C117200	Cake and Pastry Manufacturing (Factory-based)
			C117300	Biscuit Manufacturing (Factory-based)
			C117400	Bakery Product Manufacturing (Non-factory-based)
		C118	Sugar and Confectionery Manufacturing	
			C118100	Sugar Manufacturing
			C118200	Confectionery Manufacturing
		C119	Other Food Product Manufacturing	
			C119100	Potato Crisps and Corn Chips Manufacturing
			C119200	Prepared Animal and Bird Feed Manufacturing
			C119900	Other Food Products Manufacturing n.e.c.
	C12	Beverage and Tobacco Product Manufacturing		
		C121	Beverage Manufacturing	
			C121100	Soft Drink, Cordial and Syrup Manufacturing
			C121200	Beer Manufacturing
			C121300	Spirit Manufacturing
			C121400	Wine and Other Alcoholic Beverage Manufacturing