Carbon Footprints in the New Zealand Dairy Industry:

A comparison of farming systems.

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Environmental indicators which measure the energy required to produce one tonne of milk solids under the production processes of the New Zealand dairy industry are available at the macro level. However, where intensification of the industry is occurring at different rates and different localities within New Zealand, using indicators which are based on national averages may not be the most accurate way of assessing the environmental impacts associated with dairy production.

Further to this, where there is increasing scrutiny in export markets of the environmental impacts of dairy production processes, there is also an increasing reliance on information systems by consumers to assess these environmental impacts when purchasing dairy products. Macro level indicators may no longer be credible where there is increasingly disparity in the production processes of the New Zealand dairy industry.

This research used Life Cycle Analysis to estimate the energy requirements and associated carbon dioxide emissions for dairy production under three different management regimes at the farm scale. The three farm management scenarios were defined to represent the intensification and expansion which has occurred within the industry over the past decade. Scenario One represented a production system which was typical of dairy farming in the Canterbury region. The second Scenario was modelled on production under a management regime which used conventional dairy farming practices and was located in the Mackenzie Country. Scenario Three was also located in the Mackenzie Country but used a farm management regime which was supported by housing the milking herd in a “herd home” for the majority of the year.

Although the current format of industry knowledge precluded quantifying all the crucial variable and linkages within the specific farm management regimes, the conclusions drawn from the analysis were that the total quantity of primary energy required to produce one tonne of milk solids is increasing as the production processes intensify within the New Zealand dairy industry; and subsequently, developing credible indicators of energy use at the farm scale would enable the dairy industry to participate in the eco-labelling information systems in export markets.

Keywords: Environmental indicators; primary energy; dairy production; management regimes; Life Cycle Analysis.

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Executive Summary

- There is increasing scrutiny in export markets of the environmental impacts of processes associated with producing dairy products, and subsequently there is an increasing reliance on information systems by consumers who are attributing non-economic values to dairy products when making purchasing choices.
- Environmental indicators which measure the energy required to produce one tonne of milk solids under the production processes of the New Zealand dairy industry are available at the macro level. However, where intensification of the industry is occurring at different rates and in different localities within New Zealand, using indicators which are based on national averages may not be the most accurate way of assessing the environmental impacts associated with dairy production.
- Examination of structural changes which have occurred in the New Zealand dairy industry recently, highlighted that not only have the number and size of herds increased; the regional distribution of dairy herds has also changed, including production in areas which were not previously used for dairying.
- The intent of this research was to use Life Cycle Analysis (LCA) to estimate the primary energy requirements and the associated carbon dioxide emissions, for dairy production under differing management regimes at the farm scale; to determine how energy requirements for producing one tonne of milk solids differ under alternative management regimes and between different locations. Although LCA has become an internationally accepted framework for deriving environmental indicators, the subjective limitations of the approach were acknowledged during interpretation of the results.
- Three alternative management regimes were defined to represent the intensification and expansion of the dairy industry. Scenario One represented a production system which was typical of dairy farming in the Canterbury region. The Second Scenario was modelled on production under a management regime which used conventional dairy farming practices and was located in the Mackenzie Country. Scenario Three was also located in the Mackenzie Country but used a farm management regime which was supported by housing the milking herd in a “herd home” for the majority of the year.

- Although the current format of industry knowledge precluded empirical analysis of the two Mackenzie Country Scenarios, the conclusions drawn from this research included that the total quantity of primary energy required to produce one tonne of milk solids is increasing as the production processes intensify within the New Zealand dairy industry; and the key inputs which contribute to this increase in energy requirement are electricity and fertilizer.
- Developing a monitoring programme to measure the energy required in dairy farming systems at the farm scale and the associated carbon dioxide emissions, would provide credible indicators to enable the dairy industry to participate in the eco-labelling information systems in export markets, and would support policy initiatives to manage the “clean and green” promotional strategy of the dairy industry.

Chapter 1

Introduction

Research conducted in 2006 showed that the energy required to produce and export one tonne of milk solids from New Zealand to the United Kingdom is half that of the energy required to produce one tonne of milk solids in the United Kingdom (Saunders *et al.*, 2006).This research was initiated to assess the relevance of using "food miles"[1] to measure the environmental impact associated with dairy products available to consumers. It concluded that "food miles", which only considers the distance involved in transporting a product to the market, is a misleading indicator of total energy required to produce the product.

This macro level comparison of energy requirements was based on a Life Cycle Analysis of dairy production using national averages for the input inventory (Saunders *et al*., 2006). However, the New Zealand dairy industry has undergone a rapid change in structure over recent years. Not only have the number and size of herds increased; the regional distribution of dairy herds has also changed, including production in areas which were not previously used for dairying (Dairy NZ, 2009). Subsequent research conducted for the Ministry of Agriculture and Forestry has shown that, along with this variation in the regional structure of the dairy industry, there is also regional variation in the productivity of dairy animals (Clark, 2008). Clark argues that using national average indicators may not be the most accurate way of assessing the environmental impacts associated with dairy production as precision may be lost during the process of aggregating data.

The intent of this dissertation was to use the analytical framework adopted by Saunders *et al.* (2006), to estimate energy requirements and associated carbon dioxide emissions for dairy production under differing management regimes at the farm scale. This approach was adopted to determine how environmental indicators[2] vary under different management regimes and between different regions; and to assess if these indicators derived from production at the farm scale are consistent with indicators derived from analysis at the macro level.

This Dissertation is presented in seven chapters. Chapter Two provides an overview of how the global dairy industry has changed, both in terms of supply and demand, and thus sets the context for gauging the structural changes which have occurred within the New Zealand dairy

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[1] "Food miles" is the distance a product has to be transported between production and consumption.

[2] Environmental indicators provide a summary of the change in environmental impacts associated with an activity, and indicate whether impacts are progressing or regressing (Advisory Committee on Official Statistics, 2009).

industry. Chapter Three highlights the changes which have occurred in the structure of the New Zealand dairy industry and the implications of this structural change are discussed. Chapter Four reviews recent literature and establishes the validity of the Saunders *et al*.(2006) research methodology and conclusions, and also shows how this research is consistent with the approaches taken and with the conclusions reached in similar research. The methodological framework for LCA has been defined in four stages within this chapter, and the process for using LCA is specified within these stages: Purpose and scope; Inventory analysis; Impact Assessment and Interpretation.

Chapter Five defines the purpose and scope of estimating the energy requirements and carbon dioxide emissions for dairy production under differing management regimes and documentation of how data was collected and analysed is provided. Chapter six provides an interpretation of results and these are qualified by the limitations encountered during the research process.

Chapter Seven draws on the findings of the analysis and discusses the results within the context of the structural changes which have occurred with the New Zealand dairy industry, and with regard to the implications of increased reliance on information systems within export markets. This research supports the conclusions that the total quantity of primary energy required to produce one tonne of milk solids is increasing as the production processes intensify within the New Zealand dairy industry, and developing credible indicators of energy use at the farm scale would enable the dairy industry to participate in the eco-labelling information systems in export markets.

Chapter 2

The Global Dairy Industry

2.1 Global Supply of Dairy Products

Global production of milk has shown steady growth over the last two decades, accompanied by increasingly industrialised production processes (FAO, 2009). Economic globalisation and International Free Trade Agreements have allowed consolidated corporate control to increase the concentration and specialisation of milk production in an industrialised manner, leading to more intensive dairy production regimes (Filson, 2004; Bewsell, 2008). However, trends in structural change within the industry are not consistent across regions. Production quotas in Europe have constrained European milk supply, whereas there are no quotas restricting the levels of production in New Zealand, Australia and Korea and these countries have recorded strong growth in Milk production (OECD, 2004).

The European dairy industry has experienced consolidation of milk production, exhibiting trends towards more capital intensive and larger scale operations where technological advances in milking procedures and farm management practices have enabled higher volumes of production per cow and per hectare (OECD, 2004). Increased productivity has also occurred outside Europe where milk production processes are becoming more industrialised as well, with higher stocking rates and more intensive management regimes (OCED, 2004). In addition, these regions have recorded growth in production through expansion of the land area used for dairying (OECD, 2004). The structure of the global dairy industry has changed, both in terms of the scale of the milk production enterprises as well as in the total area of land used for production.

2.2 Global Demand for Dairy Products

Concurrently, the structure of export markets for dairy products has altered over the last decade, reflecting variations in the demand for milk products between different regions of the global market. A large share of the worldwide production of milk is consumed within countries where the milk is produced, to the extent that international trade in dairy products represents less than 10 percent of global production (FAO, 2009). Milk consumption is relatively stable in OECD countries, whereas in non-OECD countries, such as India and China, there is strong growth in milk consumption which exceeds domestic supply (OECD, 2004). Growth in demand for dairy products in developing countries is expected to continue at the rate of at least 3 percent per annum over the next decade, with the main drivers in demand being increasing population, higher incomes and urbanisation (Bewsell, 2008).

2.2.1 The Greening of the Market

Segments of export markets for dairy products are attributing non-economic values to products. OECD research concludes that there is an increase in market concern over the impact of milk production on water pollution, ecosystem biodiversity and landscape values (OECD, 2004). Consumers are becoming more aware of the processes involved in milk production, including how different levels of intensity in production contribute to varying impacts on the environment, and this awareness is being translated into purchase choices (Woolverton, 2010; Bostrom, 2009). Consumers are expressing non-economic values such as human rights, animal rights and environmental responsibility in the market place and are attaching an attribute of “greenness” to products (Bostrom, 2009).

Even though global demand for dairy products is expected to grow over the next decade, the increasing focus on product attributes, such as “greenness”, is changing the structure of the demand market and, subsequently, changing the framework for the competitive advantage of producer countries in the market place. Products are being differentiated by perceived “greenness” attributes and premiums are being paid for products which are perceived as having a lesser impact of the environment (Bostrom, 2009). This concept is relevant to the New Zealand dairy industry if, for example, the New Zealand dairy production process is perceived as being less environmentally friendly than alternative dairy product sources, and therefore negatively affecting sales.

However, disconnect in consumer knowledge between production and consumption means that the dairy producer may be aware of the environmental implications of the production process, but the consumer is unable to assess the environmental externalities associated with dairy production. Attributes of a product which are considered to be “green”, are sometimes unobservable during consumption (Woolverton, 2010). The remoteness of New Zealand from the dairy product markets could exacerbate this disconnect between production and consumption and this would be a case of market influence being underscored by asymmetrical information where the true extent of externalities associated with production are not monitored and the market not informed (Woolverton, 2010). Where this imperfect market condition applies, such as in markets for dairy products, consumers cannot realistically assess the “greenness” of products whilst making a purchasing decision; and are reliant on information tools which translate the environmental attributes of a product for the consumer (Bostrom, 2009).

Both regulatory and consumer systems are developing in the marketplace to redress this imbalance in market knowledge. To this end, tools such as food safety standards, eco-labelling and “food miles” have evolved to allow consumers to evaluate the “greenness” of products (Woolverton, 2010). Over half German and French consumers consider “certification marks” to assess whether a product is environmentally friendly when purchasing (European Commission, 2010). An example of an initiative for using product labelling to inform consumers about environmentally-friendly products and practices is the website www.greenchoices.org which focuses on providing environmental indicators for food products. Labels target various aspects of products, such as the environmental impact of production or transportation, and are designed to enable consumers to make decisions based on the impacts of their purchases. The knowledge imbalance of environmental impacts between dairy producers and the consumers is being reduced by these information tools.

Applying credible and scientifically robust environmental indicators to dairy products is difficult where the environmental problems caused by dairy production systems are complex and, to a large extent, ill-defined. Designing indicators becomes even more complex when placed in the context of the social construct of the supply chain (Bostrom, 2009). A report commissioned by the British Department of Environment, Food and Rural Affairs into the validity of “food miles” as an indicator of sustainability suggested that a more complex “suite of indicators” looking at a wider range of issues was necessary to better understand the environmental impact of food consumed in the UK (AEA Technology Environment, 2005). This conclusion was supported by research conducted in New Zealand which used Life Cycle Analysis to compare the energy consumption and carbon dioxide emissions associated with dairy production and transport in the UK and New Zealand (Saunders *et al.*, 2006).

Information systems are potentially a vehicle for adding a further political dimension to the market place. Labelling can be seen to empower the consumer; however this empowerment is framed by the driving forces and institutional structures which design the systems (Bostrom, 2009). Retailers, such as the Waitrose supermarket chain in the UK, are adopting eco-labelling as a strategy to become established in the growing market for “green” products (Waitrose, 2010). The potential exists for the capture of the eco-labelling process by business organisations for use as a strategic marketing tool rather than for underscoring environmental stewardship (Kemp, 2010). Potentially, information systems could empower retail chains as gatekeepers to the market where the retailers set the criteria for product labelling. For example, the Waitrose supermarket chain has a company policy of not selling butter which is produced by New Zealand dairy production systems which house cattle indoors for a substantial part of the year (Waitrose, 2010). Subsequently, retailers could use eco-labelling as a trade barrier to export markets for dairy produce even though the New Zealand dairy industry uses the "clean and green" image to promote their products in these markets (Fonterra, 2010).

The perception of New Zealand dairy products as being "clean and green" will be further undermined by reports such as the OECD *Environmental Performance Review of New Zealand* which states that "*changes in agricultural production have led to increased intensity of inputs, including fertilizer and irrigated water with consequent increase in environmental pressure"* (OECD, 2007:7).This report concludes that New Zealand, including the dairy sector, still faces the challenge to better integrate environmental concerns into agricultural production processes which contribute 50 percent of the nation's Green House Gas (GHG) emissions, and this contribution is still increasing with the intensification of farming. The conclusions reached by the OECD could undermine the promotional 'clean and green" strategy of the New Zealand dairy industry.

The UK media have also singled out the growing GHG emissions level associated with agriculture in New Zealand. A recent article in the *UK Guardian* claimed that New Zealand is not meeting the commitments made under the Kyoto Protocol, drawing on United Nations statistics to show that emissions of GHG are up by 22 percent on the 1990 levels (Pearce, 2009). Pearce claimed that emission levels in New Zealand are 60 percent higher than the UK per head of population and claimed that New Zealand's "clean and green" image is commercial green-wash. The *UK Guardian* is a national newspaper with a daily circulation of nearly 300,000 (Guardian, 2010), so the claims made in this article could undermine the promotional strategy of the dairy industry.

The "clean and green" image promoted by the New Zealand dairy industry could be tarnished if consumers in export markets make a connection between the environmental impacts of production systems in their local country with similar systems in New Zealand. There has been recent public dissent in the UK over an application to establish a dairy enterprise which houses over 8,000 cows in an indoor facility. Community concerns include waste management, animal welfare and effects on the local environs (Tasker, 2010). A connection could be made between this intensive British operation and a similar intensive dairy operation recently proposed for the Mackenzie Country of New Zealand (Environment Canterbury, 2009), an area that has not traditionally supported dairy production and which the Parliamentary Commissioner for the Environment states is an iconic landscape (PCE, 2009).

Consumers are attributing non-economic values to dairy products and where information systems are developing within export markets, including eco-labelling, indictors are becoming available to rank the environmental impacts of producing dairy products in the country of origin. New Zealand dairy exports will be subject to consumer scrutiny based on these information systems, with potential to undermine New Zealand export sales.

2.2.2 International Environmental Institutions

Not only is there commercial pressure for New Zealand to improve environmental performance, the New Zealand dairy industry is also facing regulatory pressure to improve environmental stewardship associated with dairy production (Jay, 2007). Increasing international and domestic political pressures have supported the advent of a regulatory framework for reporting on environmental indicators at the national level. The Greenhouse Gas Inventory measures New Zealand’s progress towards its obligations under the Kyoto Protocol and the United Nations Framework Convention on Climate Change (MfE, 2010). Results feed into comparative analyses such as the OECD *Environmental Performance Review,* and are available to international media (OECD, 2007; Pearce, 2009). Both the OECD report and the Guardian article (Pearce, 2009), highlight the growing level of GHG emissions in New Zealand over recent years and emphasise that this trend is counter to commitments under the Kyoto Protocol to reduce GHG emissions. These outcomes have negative implications for New Zealand’s “clean and green” image in the market place as well as having possible political and financial ramifications under international environmental agreements.

Other international initiatives are gaining momentum to institutionalise the procedures for developing environmental indicators. The World Business Council for Sustainable Development and the World Resources Institute have developed and published standards under their GHG Protocol initiative; the United Nations Environmental Protection group has launched a project on “carbon foot-printing”[3]; the British Standards Institution has published requirements for assessing life cycle GHG emissions; and the European Commission has produced a “carbon footprint measurement toolkit” for the European Union Eco-label, just to name a few recent developments (Finkbeiner, 2009; Europa, 2010; European Commission

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[3] “Carbon foot-printing” is a term which refers to the carbon dioxide emissions (or equivalents) which are associated with an activity. For example: producing one tonne of milk solids.

DG ENV, 2009). These initiatives have evolved to serve an increasing demand for information on the environmental impacts of production and are influencing the structure of export markets (Finkbeiner, 2009).

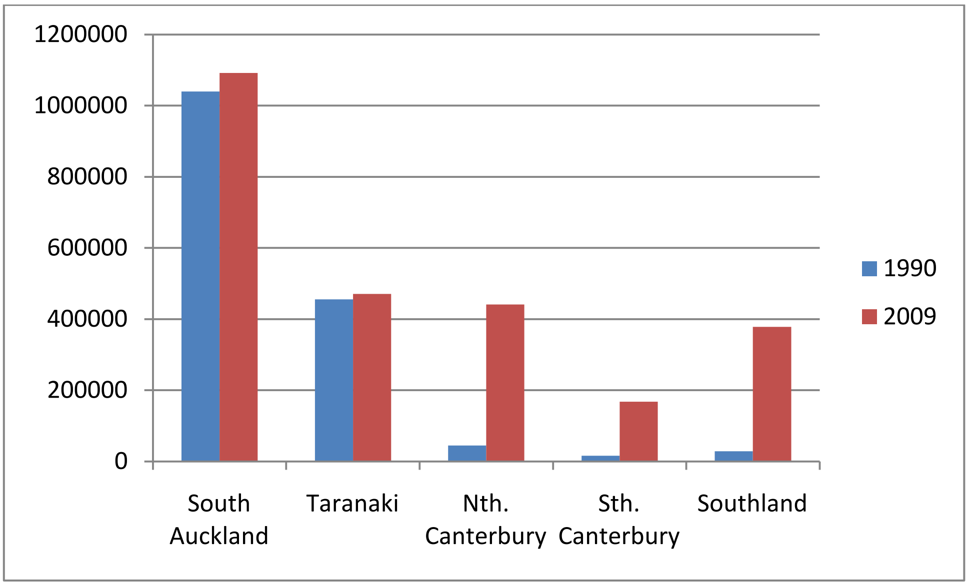
Chapter 3

Changes in the Structure of the New Zealand Dairy Industry

Approximately half New Zealand's GHG emissions can be attributed to the agricultural industry, of which the dairy sector is a significant component (MfE, 2010).The New Zealand dairy industry is the world's largest exporter of milk products, supplying nearly a third of the volumes traded internationally (FAO, 2007). In terms of exports as a percentage of production, New Zealand is the highest global exporter with 70% of production being exported (OECD, 2007).

Volumes of milk solids produced have increased by 60 percent over the last decade. This growth has been supported by an expansion in the land area used for dairying, as well as more intensive farming practices (Dairy NZ, 2009). Specifically, over a third of the 4.2 million dairy cows in New Zealand are now located in the South Island, whereas less than 10 percent of the national herd was milked in the South Island ten years ago. The variation in the regional growth of cow numbers is portrayed in Figure 1.

Figure 1: Number of Dairy Cows in Selected Regions

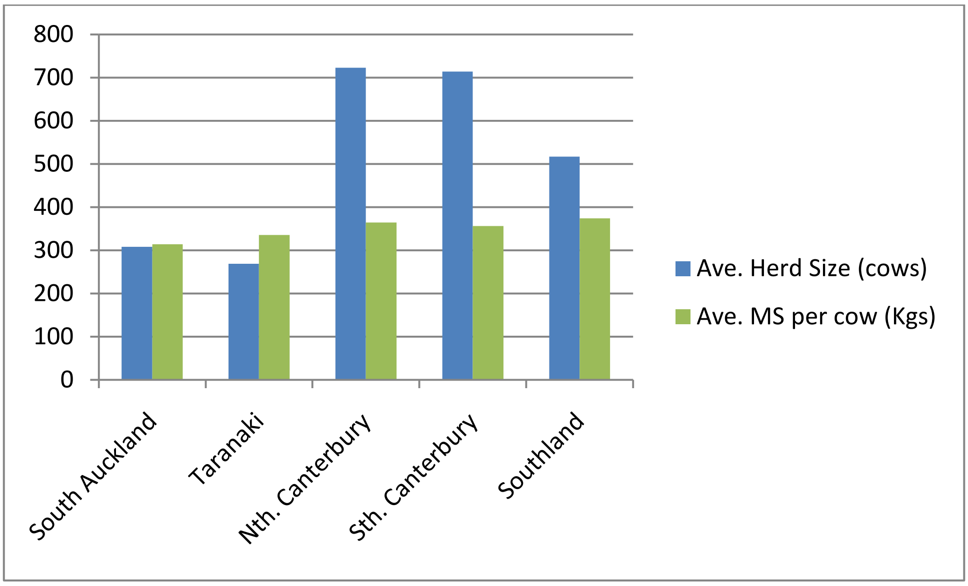


Source: Dairy NZ (2009)

The Canterbury and Southland regions have experienced strong growth in the number of dairy cattle. Cattle numbers in these regions have increased tenfold over the past two decades. In comparison, the number of dairy cattle in South Auckland and Taranaki has remained relatively stable over the same period. This growth in the South Island has been supported by increased volumes of irrigated water, fertilizer applications and the conversion of land use from other productive enterprises, including less intensive sheep and beef farming, to dairying (PCE, 2004).

Dairy industry statistics indicate that there is also regional variation in the scale of farming and the productivity of dairy herds (Dairy NZ, 2009). These variations are highlighted in Figure 2.

Figure 2: Regional Production Indicators



Source: Dairy NZ (2009)

The scale of dairy farms in the South Island is larger than that of the North Island, with herds twice the size of herds located in the more traditional dairy farming areas of South Auckland and Taranaki. Stocking rates are also much more intensive in the South Island. The national average stocking rate is 2.83 cows per hectare, whereas in Canterbury it is 3.25 cows per hectare (Dairy NZ, 2009).

Farm management regimes and the physical attributes of farms vary between regions, which can contribute to variations in regional productivity. Despite the fact that dairy farming in the South Island is on a larger scale and higher stocking rates than in the North Island, on average the South Island dairy herd produces more milk solids per cow than its North Island counterpart (Dairy NZ, 2009). Production variables, such as grazing management and the quality of supplementary feed, influence the metabolic efficiency of dry matter conversion by a cow which predicates cow productivity (Holmes, 2002). Productivity is also influenced by the length of the lactation period for the herd, and in Canterbury extensive use of centre pivot irrigation has enabled a longer period of pasture growth than under non-irrigated management regimes (Pangborn, 2010; Holmes, 2002).

Dairy industry structural change has been supported by more intensive use of resources**,** including inputs such as fertilizer, energy and water, as well as capital assets including land and stock (PCE, 2004). Comparing the production parameters of the South Island with those of the North Island indicates that changes in management regimes have not been consistent within the dairy industry and this has led to regional diversity in the intensity of resource use (PCE, 2004).

In conclusion, dairy production systems are not the same across regions and the variations in production systems reflect the unique biological ecosystems in a region and the specific management regimes adopted by farmers (Horne, 2009).

3.1 The Implications of Structural Change in the Dairy Industry

Increasingly intensive farming regimes require higher inputs of feed, fertilizer, water and energy and this intensification loads extra pressure on the environment to assimilate wastes discharged to the land and atmosphere. Intensive agriculture releases significant amounts of nutrients, including nitrogen and phosphorous, faecal bacteria and sediment to the environment and, as farm inputs increase and systems intensify, the loading on the environment to assimilate waste also increases (Monaghan, 2008). The consequence of this added loading on ecosystems to assimilate wastes includes nutrient enrichment of the ground and surface water (Monaghan, 2008). Higher stock numbers also contribute to increased GHG emissions by way of higher methane and nitrous oxide emissions (MfE, 2010).

Intensification with greater levels of inputs for dairy production, such as fuel, fertilizer and water, also increases the energy requirements for production processes. For example, energy is used indirectly in the manufacture of fossil-fuel based fertilizer and, correspondingly, the more intensive the fertilizer regime, the higher the primary energy [4] content of fertilizer applications (PCE, 2004). However, indicators which measure intensity of application or energy use are not necessarily synonymous with measuring energy efficiency. Efficiency is a measure of energy consumption per unit of output, and efficiency indicators reflect improvements in technology, and the management decisions which result in better systems and processes (EECA, 2004).

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[4] Primary energy is the inherent energy in a product plus the energy required to extract, produce and transport the product to the point of consumption.

Issues of efficiency in energy-use could be problematic for the dairy industry because scarcity of fossil resources is of global concern, and because information systems in the market place focus on the energy requirement and carbon emissions associated with dairy products (Monaghan, 2008; Woolverton, 2010). Eco-efficiency indicators provide estimates of the environmental impact of production, and an indicator which estimates the energy required to produce a unit of product informs a consumer of the relative demands the production process puts on the limited fossil resources. It therefore provides a tool to compare the energy efficiency of the production processes associated with products, and deriving primary energy and associated carbon emission indicators for dairy production systems is more relevant for market information systems than providing simplistic indicators of energy use such as “food miles” (Andrew, 2006; Saunders, *et al.*, 2006; Schmidt, 2009).

Chapter 4

Farm Scale Environmental Indicators for the Dairy Industry

A number of studies have been undertaken at the national level using dairy industry averages to reflect the environmental impacts of dairy farming systems (Andrew, 2006; Barber, 2005; Basset-Mens, 2007; Saunders *et al.*, 2006; Wells, 2001). By their nature, these studies hide variations in regional climatic conditions, land type and management systems, which all influence environmental impacts (Andrew, 2007; Clark, 2008; Carran, 2004; Pinares-Patino, 2009). Where farm scale studies have permitted comparisons, they have concluded that there is significant variation in effects between dairy farms (Basset-Mens, 2007; Clark, 2008; Wells, 2001).

Contemporary international studies also support the conclusion that variation in estimated environmental impacts is greater when analysed at the farm scale rather than at the macro level (Cederberg, 2003; Rotz, 2010; Schils, 2007; Walsh, 2009). The variations in physical and management characteristics of specific farms, not just the production systems which have been adopted, contribute to variations in the environmental impacts at the local level (Brentrup, 200; van der Werf, 2007). Deriving environmental indicators at the farm scale requires detailed specification of the variables supporting the production process.

However, the method of evaluating the environmental impacts can also contribute to the estimated variation between farms (Bentrup, 2000; Rotz, 2010; Schils, 2007; van der Werf, 2007). For example, "Whole Farm Models" [5]assess the environmental implications of alternative farm management strategies at the farm scale but do not take into account possible transfer effects of environmental impacts from inputs brought into the farming systems, or products exported from the system (Schils, 2007; Thomassen, 2008). Life Cycle Analysis (LCA), on the other hand, assesses the environmental impact associated with a product throughout its life cycle and in doing so, recognises the interconnections between processes inside and outside the physical farm boundary (Berlin, 2003; Finnveden, 2009; Horne, 2009). LCA incorporates the indirect environmental impacts of the production process, whereas under a whole farm approach, these impacts would be considered outside the scope for analysis.

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[5] Whole Farm Model represents the systems within the physical boundary of a farm.

LCA is one of the most commonly used approaches for evaluating environmental impacts of production processes (Berlin, 2003). The principles and procedures for LCA have been standardised by the International Organization for Standardization (ISO) specifications and extensive peer reviewed publications support the concept as a tool for environmental impact assessment (Ciroth, 2006; ISO, 2006). LCA, supported by an inventory of inputs and outputs used in the production process, has become an accepted framework to collate environmental indicators for agricultural production systems, and for presenting valuable insight into the environmental impacts of the dairy industry (Horne, 2009; Thomassen, 2005; Schils, 2007). These conclusions support the approach taken by Saunders *et al.* (2006) in using LCA to measure the environmental impact of dairy production systems in New Zealand.

4.1 Life Cycle Analysis

International standards have been developed over the past decade to assist in the specification, definition, methodology and protocols for use and review of LCA (Horne, 2009). ISO 14040 defines the principles and framework requirements, and ISO 14044 specifications provide the requirements and guidelines for a standardised approach for LCA. These specifications also provide the critical review parameters and limitations of LCA (Berlin, 2003). This standardised approach allows for a direct comparison of the environmental impacts associated with production processes between different farming systems, at the farm scale, national scale or at an international level.

The underlying principle is that all inputs and outputs associated with production, transportation, consumption and waste management are assessed and involve quantification of a product’s requirements for energy and resources, and the emissions and wastes released to the environment (Berlin, 2003). The standardised procedure for LCA consists of four stages (Berlin, 2003).

Stage 1: Defining the purpose and scope of the analysis specifies the boundaries of a production system within which all inputs and outputs are assessed. The functional unit on which the analysis is based to derive an environmental indicator is also defined. For example, in the Saunders *et al*. (2006) research the functional unit is one tonne of milk solids delivered to the UK.

Stage 2: Inventory analysis identifies and quantifies all inputs and outputs required during the life cycle of the product.

Stage 3: Impact assessment of the resources used in production to link the environmental impact of production to specific inputs used in the process. For example, the contribution of the primary energy of specific inputs to the cumulative energy requirements for the product.

Stage 4: Interpretation of how the inputs in the production process cumulatively impact on the environment and identifying which inputs are key contributors to the cumulative impact. Further, this stage assesses the integrity of the analysis by evaluating the accuracy and completeness of supporting data.

Comparability of analyses is dependent on the similarity of the boundaries for the Life Cycle of products. The validity of comparing LCAs is higher where the boundary definitions are the same (Berlin, 2003). Table 1 lists the criteria for boundary definition relevant to LCA.

Table 1: Criteria for Defining the Systems Boundary for LCA

- A specified time frame during which data representing the production system/s is collected.
- The geographical area to which the data are relevant.
- Specification of the type of technology involved in the production process.
- How precisely the data represent the production system.
- How complete the data set is to provide a simulated model of the production system.
- How representative the data set is of the systems boundary of the production process.

Source: Berlin (2003)

The ISO standards provide a framework for defining the parameters of an analytical model which is assumed to mimic a production system. The accuracy of the parameters that describe the production process, as described in Table 1, determines how well the model reflects reality, and how valid direct comparison is with other production systems.

4.2 Limitations in using LCA

Although LCA has become an internationally accepted framework for deriving environmental indicators, there are limitations to using this approach. Studies which have used LCA as a tool to compare dairy production systems in different countries have highlighted that further standardisation of procedures is required to validate comparison between production systems (Baseet-Mens, 2007; Brentrup, 2000; Cederberg, 2003; Ciroth, 2006; van der Werf *et al*., 2007).

Under the ISO standards there is no specification on the spatial and temporal boundaries for LCA and boundary definitions are based on subjective judgements of the analyst (Finbeiner, 2009). Temporal boundaries can be ambiguous, especially in agricultural systems where the time frame for the analysis may exclude environmental impacts from activities such as land conversion and pasture development, even though these activities have contributed to the production system (Horne, 2009). Defining the boundaries of analysis for agricultural systems is complex and boundary definition based on subjective judgements can introduce inconsistencies in the inventory analysis preventing valid comparison between models (Finbeiner, 2009, Thomassen, 2008).

Inconsistency in completeness and source of data sets, has also been identified as a limitation to using LCA for comparative studies in the dairy industry (Basset-Mens, 2005; Brentrup, 2000). As dairy production systems are reliant on complex and interconnected ecosystems which are influenced by humans, animals and the environment, the identification and quantification of inputs is not always possible and the treatment of uncertainty has been problematic (Basset-Mens, 2009). Where secondary sources of data are incorporated into LCA, the data are assumed to be representative of the production system being evaluated. Data values derived from literature often reflect a derived average for the system based on previous primary research where the boundary definition may be different to system being analysed. Quality of the data depends on the relevance of the time frame difference and the quality of the literature source (Brentrup, 2000). Using the triangulation[6] concept, results from other comparable studies can provide an indication of the reliability of the data, but provides only a partial approach to validation of the LCA model (Ciroth, 2006).

Each LCA model is designed to mimic the production system being evaluated. However, due to the bio-physical nature of dairy production systems, it is difficult to validate how accurately a model reflects reality (Ciroth, 2006). Validation of a model is an essential element in

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[6] Triangulation in research refers to the use of several sources of information to verify a claim.

assessing a model’s reliability and relevance in evaluating environmental impacts. Scientific criteria for assessing the validity of a model include empirical testing, full documentation, reporting of uncertainty, peer review and open debate (Ciroth, 2006). Empirical testing of LCA is usually only conducted for single elements of the model, and LCA protocols do not require empirical testing of the complete model (Finnveden, 2009). Further to this, full reporting of uncertainty during LCA is usually incomplete and open debate of the model parameters is sometimes limited by confidentiality issues surrounding access to primary data (Ciroth, 2006, Finnverden, 2009). The validity of environmental indicators derived using LCA is difficult to assess using scientific criteria, however full documentation of assumptions and data sources used in LCA goes some way to mitigating the limitations of LCA (Horne, 2009).

Van der Werf *et al*. (2007) also highlighted that for indicators derived from the environmental impacts of production to be reliable, indicators should be interpreted within the context of the original purpose for analysis, with a clearly defined boundary for analysis and with a specified functional unit. Attributing environmental indicators to dairy products is as much about communicating to the consumer what the indicator represents, as it is about providing a quantitative value to ensure that the comparison of product indicators is relevant (Heink, 2010).

Chapter 5

The New Zealand Dairy Industry Model

Although the process of LCA is based on the empirical analysis of a product's life cycle, the previously identified limitations are in effect generated by subjective judgements made during the analysis. To recap, highlighted limitations to LCA include ambiguity in research purpose; inconsistency in boundary definition; and irregularity in completeness and source of data sets. In acknowledging that subjectivity was an inherent part of LCA analysis, five criteria were defined to measure the integrity of this research; and where possible, to frame methods for mitigating the limitations. These criteria are modified from a checklist derived by O'Leary (2009) for designing sound methodology and are recorded in Table 2.

Table 2: Criteria by which to Measure Research Integrity

Source: O'Leary (2009)

1. Subjectivity: is acknowledged as being incorporated into the research definition and process, and collection and interpretation of empirical data is subject to the researcher's interpretation of the relevance and reliability of data sources. The researcher has a secondary understanding of the dairy production systems and industry structure, and this knowledge is built on by discussion with industry experts and literature investigation.

2. Validity: The methodological approach taken by contemporary peer reviewed research provides the framework for research methods, and reference back to peer reviewed research provides a means of validating the relevance of the approach and methods adopted in this research. Any deviation from this research framework is to be considered during discussion of results.

3. Reliability: A systematic and consistent method for data collection is adopted and documented to allow for transparent and replicable research processes. Where inconsistency in data collection and analysis is not possible, research results are interpreted within these limitations.

4. Transferability: It is acknowledged that agricultural systems are complex and comprise interconnected ecological and human systems. The context of production systems for analysis are clearly delineated, and where the empirical data used to define the systems are incomplete, discussion and conclusion will avoid transposing analytical results between scenarios.

5. Reproducibility: Full documentation of research methods is available to support a transparent and replicable research framework

These criteria were used to define the research methodology and also as a means to critically evaluate the results of analysis.

The methodological framework for this research followed the ISO standardised procedure for LCA, as described by Berlin (2003). This approach has become an accepted framework for evaluating the environmental impacts associated with agricultural production systems and it provided a transparent and replicable research framework.

5.1 Stage 1: Purpose and Scope of the Research

Previous discussion has identified that export markets are becoming increasingly reliant on information systems which inform consumers of the environmental impacts associated with dairy products. The New Zealand dairy industry is dependent on these markets for the bulk of its dairy sales and where the structure of the dairy industry is changing, so too are the environmental impacts associated with production. Environmental indicators for dairy products are available at the macro level; however, as the industry structure is becoming more disparate, the provision of environmental indicators at the farm scale could become an increasing requirement for exported dairy products to meet retailer and consumer demand for information on the environmental impacts of dairy production.

The purpose of this research is to measure energy use and carbon dioxide emissions under different dairy farm management regimes to determine how the changing structure of the New Zealand dairy industry is changing the energy use and carbon emissions of production.

5.1.1 The Research Template

The literature reviewed in Section 4 supports the approach taken by Saunders *et al*. (2006) in evaluating energy use and carbon emissions at the macro level and this analytical framework is consistent with the ISO standardised procedures. Subsequently this approach was selected as the template for empirical analysis to compare an average New Zealand farm and alternative farming regimes at the farm scale. The empirical data used to support comparative analysis was taken from the updated version of this report (Saunders, 2007).

The Saunders *et al*. (2006) framework used a truncated LCA which measured impacts from the cradle to the farm gate plus international transport. Resources required for transporting and processing dairy products between farm gate and export port were assumed to be similar to the resources required for internal transport and processing in importing countries, and both were excluded. The disposal and waste management phase of the product life cycle was also omitted from the analysis on the assumption that competing products consumed in export markets were subject to the same disposal process. The system boundary for dairy exports was defined by Saunders *et al*. as the cradle to the gate, excluding domestic transport but including international transport and input data was based on aggregated data sets representing the geographical areas of New Zealand and the UK. Secondary sources of data were used by Saunders *et al.* based on a combination of recent industry studies. The time frame for analysis was one year and the specification of the farming system was for an average production system for the dairy industry in 2001.

Saunders *et al* (2006) method of analysis was to systematically identify the inputs required in a typical production system within the defined system boundaries, to provide an inventory of inputs required for the production of milk solids. Conversion coefficients were applied to this inventory to calculate the energy content and subsequent carbon dioxide emissions for each input. The functional unit of production was one tonne of milk solids. The methodology was underpinned by research carried out in 2001 for the Ministry of Agriculture and Forestry which identified the primary energy and carbon emissions of dairy production inputs (Wells, 2001).

5.1.2 Model Development to Accommodate Alternative Management Regimes

The model specifications used by Saunders *et al.* (2006) were adopted as the LCA research template for this research. However, in this research the objective was to measure energy use and carbon emissions at the farm scale rather than encompassing the environmental impacts of transportation. For this reason, the system boundary for the LCA was limited to cradle to gate for each management regime analysed, and excluded inputs required for the transportation of milk from the farm and the processing of the milk into milk solids. Diagrammatic representation of the production system is shown in Figure 3.

Figure 3: Flow Chart Illustrating the Life Cycle of Milk Production: Cradle to Farm Gate

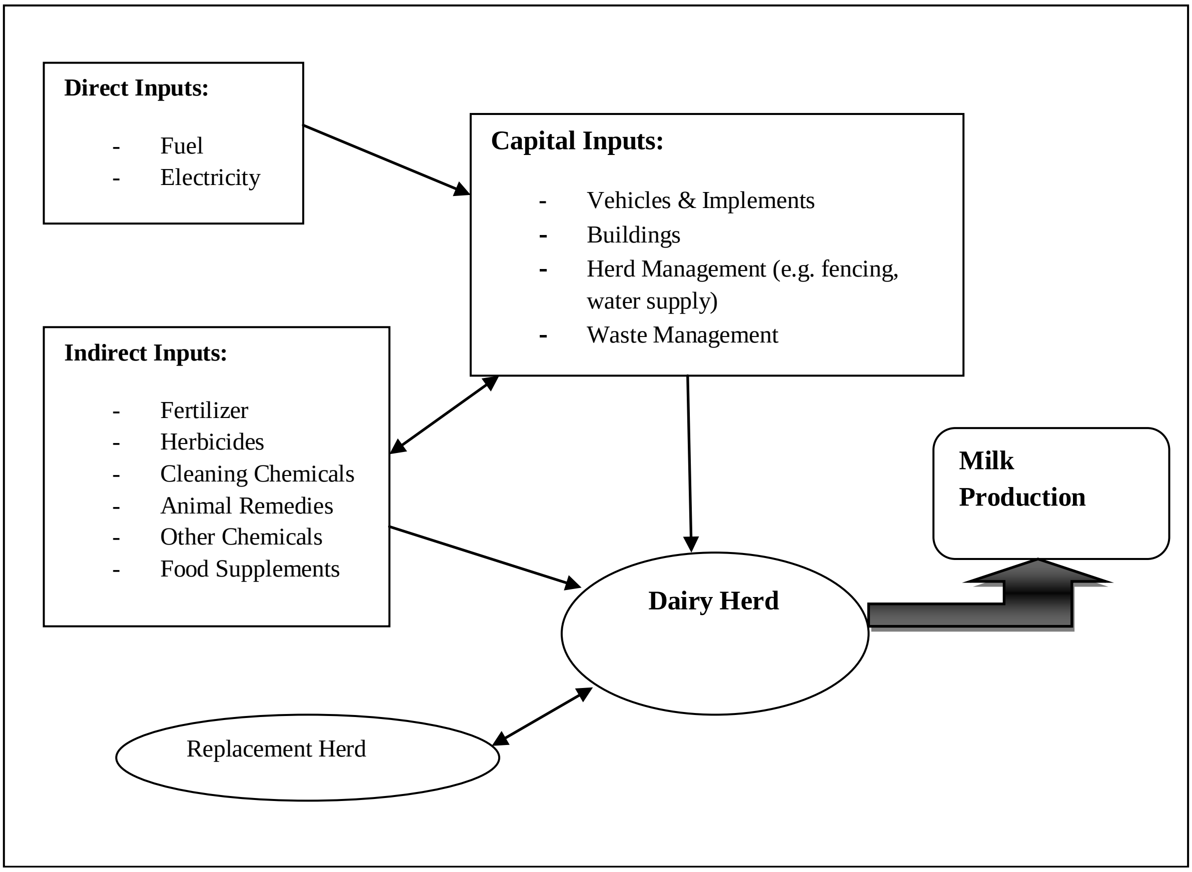

Figure 3 portrays how the boundary of the production system has been defined to include all the resources which are used directly or indirectly in the production process as well as the supporting capital infrastructure and dairy herd. These inputs represent an accumulation of the raw materials and the previous processes which have been required for the inputs to be in a form to be used in the dairy production process. Subsequently, the boundary definition encompasses the resources required for the extraction, manufacture and transportation of these inputs into the farming system.

Production systems are defined by the how technology and the differing levels of inputs are combined. Alternative management regimes incorporate different technology and infrastructure into the process and use different quantities of inputs (Homes, 2002). Direct and indirect inputs are variable within the process whereas capital inputs are considered fixed within the temporal boundary (Horne, 2009). For example: the level of electricity use reflects the extent to which the production system relies on water irrigation during the period, whereas the capital infrastructure of pivot irrigators is considered to remain the same throughout the period. Further interconnections between the production inputs are shown diagrammatically in Figure 3.The technical specifications of the alternative management regimes are define in the following section 5.1.3.

5.1.3 Definition of Farm Management Regimes

Definitions of the farm management regimes for analysis were based on earlier discussion on the changing structure of the New Zealand dairy industry where regional inconsistencies in the levels of intensification and in the growth of herd numbers were highlighted. Canterbury, in particular, was identified as having experienced strong growth in average herd size and the number of dairy cattle in the region, and the Mackenzie Country was identified as an area within this region into which dairy farming has expanded in the last decade.

The focus of this research was on farming systems in the Canterbury region, for which three farming scenarios were defined for comparison. (1) A farming system which is typical for the Canterbury region, (2) A conventional farming system located in the Mackenzie Country; and (3) A “herd home”[7] farming system located in the Mackenzie Country. Scenario parameters are listed in Table 3 and the time frame for analysis was the year ending June 2009.

Scenario One, which represents a typical farming system for Canterbury, is modelled on the annual MAF Pastoral Monitoring Programme, which represents approximately 770 dairy farms throughout Canterbury and North Otago (MAF, 2010).It represents a farm which is reliant on spray irrigation with some border irrigation and does not own a run-off but grazes some stock off the farm during the winter. This model was considered to be the most representative model of a farm in the region (Doak, pers. comm.). Pasture production equates to 11 tonnes of dry matter (DM) per hectare per year (Cameron, 2005). The replacement stock equates to 25 percent of the milking herd, with one calving per year and twice daily milking. The parameters for this model were supported by industry information which has been consistently collected over the last decade (MAF, 2010).

In the absence of published comprehensive industry information on dairy production systems in the Mackenzie Country, Scenario Two is a simulated model based on the operational plan and production parameters outlined in the Farm Environmental Management Plan (FEMP) for Glen Eyrie Downs Station in the Mackenzie Country (Ryder Consultants, 2009). This FEMP supported a resource consent application for a proposed conventional dairy farming venture

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[7] Herd homes are buildings which house stock with facilities for feeding and resting, and which have specialist effluent management systems. See www.herdhomes.co.nz

on the station and was compiled by dairy industry consultants and advisors to the industry. The farming system was described as six dairy farms which were to be managed independently. For the purposes of this research, the model was based on one of these farm units comprising 344 effective[8] hectares. Each farm unit would be managed as a conventional pasture grazing farming system and would have an area of 100 hectares set aside for harvesting silage as a supplement for off-pasture feeding of the stock. Pasture production is expected to be 14 tonne DM per hectare per year on irrigated and fertilized land. Irrigation water would be applied to the whole farm using centre pivot irrigators. All cows would be wintered off the pasture between mid-May and mid-August and the replacement stock ratio is assumed to be 25 percent of the milking herd. The management system includes one calving per year and twice daily milking.

The specifications of the farming system for the Third Scenario were also based on the Glen Eyrie Downs Station FEMP which had considered an alternative management regime of housing the dairy cows in “herd homes” (Ryder Consultants, 2009). This proposed dairy production system was adopted as the model to represent Scenario Three because there was no industry information on “herd home” production systems in the Mackenzie Country. There are a number of dairy farms in New Zealand using “herd homes” to house cattle, although only for a limited period of the year, such as during the winter months. There are currently no “herd homes” located in the Mackenzie Country. The FEMP specifications for the Scenario Three are based on transposed production expectations and parameters from dairy farming systems which incorporate housed cattle for part of the year, and which are located in South Canterbury and Southland (Engelbrecht, pers. com., 2010; Ryder Consultants, 2009). Again the production parameters were devised by industry consultants and advisors to the industry for the FEMP.

The systems definition for Scenario Three includes housing the dairy cattle in cubicle designed barns with an attached milking parlour. The cattle would be housed full time from March until October and for 12 hours a day from November till February. Pasture would be supplied to the cattle using a cut and carry regime[9] of mechanically harvesting pasture which is fed to stock as silage. Harvesting is expected to reap 85 percent of the pasture grown. The model represents a farm of 344 hectares which would support approximately 1200 milking cows. The breeding programme would support all year round calving and milking with all dry stock, including weaned stock, being grazed off the farm. The replacement stock ratio is

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[8] Effective land area is the area of a farm which is specifically used for dairy production.

[9] A cut and carry regime involves mechanically harvesting pasture as silage and transporting the silage to the housed stock for feeding where they stand.

assumed to be 25 percent of the milking herd, although this may be an over estimate for this farming system as the herd would not be exposed to extreme climatic conditions (Engelbrecht, pers. comm.). Effluent from the "herd home' would be spread by centre pivot irrigator. The solids would be spread by muck spreader or exported. Pasture production is expected to be 13 tonne of DM / ha / year and the land would be fertilized and irrigated. Nitrogen applications from organic and inorganic sources would be limited to 315 kg per hectare per year.

Table 3: Production Parameters for the Three Scenarios.

	Canterbury	Mackenzie Conventional	Mackenzie Herd Home
Effective area (ha)	210	344	344
Cows wintered (head)	733	0	1,167
Replacement heifers (head)	183	158	291
Cows milked 15th December (head)	705	633	1,167
Stocking rate (cows per ha.)	3.4	2.7	3.5
Total milk solids ((Kg)	280,123	221,550	408,450
Milk solids per ha. ((Kg/ha)	1,334	644	1,187
Milk solids per cow milked (Kg/cow)	397	350	350

Sources: MAF (2010); Ryder Consultants (2009)

Table 3 provides a direct comparison of the technical specifications for the three scenarios. The land area was greater in the Mackenzie Country than under the Canterbury model where the effective areas were 344 hectares and 210 hectares respectively. Comparison with industry statistics for 2009, showed that the average Mackenzie Country dairy farm was only 277 hectares and therefore, the model proposed is larger than current farming regimes in the area (Dairy NZ, 2010). The effective area for the Canterbury model, on the other hand, is based on the MAF Pastoral Monitoring Programme and is representative of the region (MAF, 2010).

The boundaries for the three scenarios are distinctively different. The differences in stock wintering strategies are evident from Table 3. All stock were wintered off the property to mitigate pasture damage in Scenario Two, whereas under Scenario Three, the milking herd was retained on the farm in herd homes during the winter months. These alternative wintering strategies involve different feed management practices. Both Scenarios One and Two graze stock off the farm during the winter whereas under Scenario Three, cattle are still fed by the cut and carry system on the farm.

The infrastructure required to support the three scenarios is also different. Scenario Three requires specific buildings designed to house the herd, purpose built facilities for effluent management; as well as specialised machinery and storage barns for the cut and carry regime. On the other hand, the conventional dairy systems under Scenarios One and Two require more extensive fencing, races and water supply for the stock than under Scenario Three.

5.2 Stage 2: Inventory Analysis

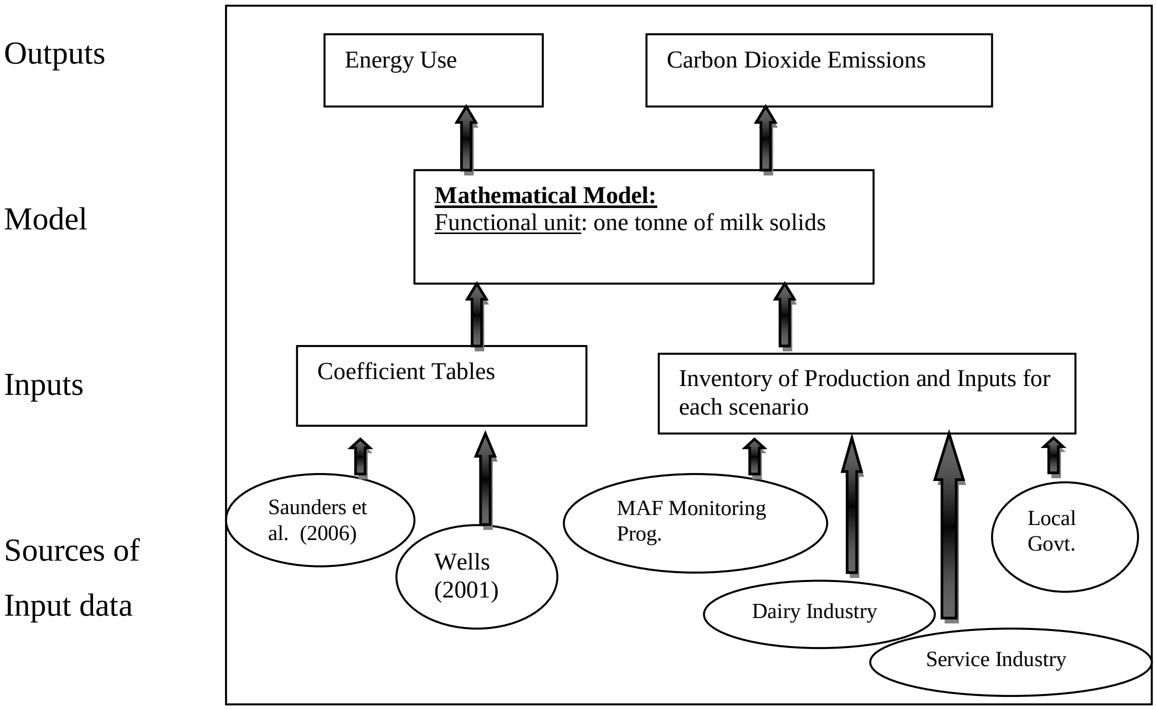
During this stage, the inputs and outputs of the dairy farming system were identified and quantified. The quantities were then prorated to quantify milk solids production per effective hectare, where the functional unit of production for analysis was one tonne of milk solids.

The inventory template was used for identifying and quantifying the inputs for the three scenarios. Use of this template provided consistency in data collection. The inventory template is appended in Table 5 (Saunders *et al.*, 2006). Where possible, the inputs for each scenario were categorised as direct inputs, including fuel and electricity; indirect inputs which included inputs such as fertilizer, agrichemicals and animal feed supplements; and capital inputs which encompassed the infrastructure required for the farming system. The quantity of inputs was then apportioned by effective hectare. The quantity of each input which was required to produce one tonne of milk solids was then calculated by dividing the inputs per hectare with the quantity of milk solids produced per effective hectare.

5.2.1 Data Collection

Initially interviews using open ended questioning were conducted with MAF personnel and dairy sectors advisors to gain insight into the linkages within the industry, and to identify credible sources of data (Doak, pers comm.; Journeaux, pers. comm..Pellow, pers. comm.) A systematic method for collecting data was then adopted to ensure consistency with the definitions and format of the research template, as defined in Table 2. Accordingly, data were collected from a combination of sources including Saunders (2007), Wells (2001), the MAF Pastoral Monitoring Programme, dairy sector advisors, supporting documentation for resource consent applications, and representatives from the dairying service industry. The framework for data collection is summarised in Figure 4.

Figure 4: Framework for Data Collection and Analysis



5.2.1.1 *The Coefficients Tables*

The coefficients used to calculate the energy content and subsequent carbon emissions of inputs were taken directly from Saunders (2007)10. These coefficients were verified by directly referring to the Wells (2001) methodology; as well as other published research on energy and carbon coefficients for inputs into the New Zealand primary sector (Barber, 2005; 2006; 2009; Carran, 2004). It was noted that all these latter reports relied on the methodology and analysis from the Wells (2001) research and so it was the empirical data which was verified rather than the underlying methodology. Although updated coefficients for fuel inputs were incorporated into the Saunders (2007) analysis, the coefficients for the remaining indirect inputs were derived a decade ago. Consequently, any changes in the primary content of indirect inputs during this time have not been incorporated into the coefficients used in the analysis.

5.2.1.2 *Data for the Three Scenarios*

The output data for the three scenarios were derived from the production parameters for each farm management regime as listed in Table 3.

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[10] Saunders *et al.* (2007) is an updated version of the Saunders *et al.* (2006) report.

5.2.1.2.1 Scenario One Input Data

Input data for Scenario One was taken from the MAF 2009 Pastoral Monitoring Programme report for the region (MAF, 2009). This information was presented in financial terms which required conversion to the physical equivalent for consistency with the inventory template.

The total cost of fuel was given as $20,400 for the financial year. This was converted from financial quantum to physical equivalents by apportioning the use of diesel, petrol and lubricants according to the weighting used for the typical New Zealand dairy farm (Saunders, 2007). Fuel costs for 2009 listed in the Farm Budget Manual for 2010, were then used to convert the use of fuel by type, from financial values to physical volumes (Pangborn, 2010a). These volumes were then attributed on an effective hectare basis.

The financial data for electricity usage were converted to physical equivalents by using the documented electricity charges for 2009 recorded in the Farm Budget Manual (Pangborn, 2010a). These physical equivalents were verified by comparing the estimated electricity costs per cow for the Canterbury region with the national average (Pangborn, 2010a). This comparison confirmed that electricity usage per hectare in Canterbury was approximately double that of the national average, and therefore the derived figure of 1292 KWh / ha was realistic.

5.2.1.2.1.1 Indirect and Capital Inputs

The fertilizer regime for the MAF model was supplied directly by MAF on a whole farm basis (Doak, 2010). These quantities were then apportioned by nutrient content on a per effective hectare basis using the chemical composition of fertilizer and the rates of application. The fertilizer regime is appended as Table 7.

Converting the financial data into physical equivalents for the other indirect inputs and the capital inputs proved to be problematic. Conversion involved aggregating inputs for some categories, and attributing regional differentials to input costs for other categories, to present the data in a format which was consistent with the inventory template. For example, it was difficult to differentiate the specific physical data for imported feed supplements. Feed prices were extremely volatile during the 2009 year due to changeable weather conditions and alternative feed supply and there was no specific benchmark for supplementary feed prices (MAF, 2010). Small bales of meadow hay were advertised for sale at $15 per bale at the beginning of June, whereas a month later the advertised price was $9 per bale (The Press, 06/06/2010; 04/07/2010). Grass silage ranged from $0.12 to $0.14 per kg/DM (Pangborn, 2010a). The availability of palm kernel also influenced the price of feed supplements during the season (MAF, 2010). The underlying rationale and assumptions adopted for converting financial input data for the remaining categories to physical equivalents are recorded in Table 8.

Although it was possible to incorporate the actual physical quantities of fertilizer used into the analysis of Scenario One, the supporting data for all other input categories required conversion from a financial format to a physical quantity. With reference to the criteria for measuring research integrity, which were listed in Table 2, the process of converting data from one quantum to another introduced subjective assumptions about the specification of the input and the conversion rate to use. Various sources of input prices were compared in an attempt to triangulate the values used in conversion, however this scoping highlighted that not only were the cost of inputs volatile during the season, but the quality of some inputs was also variable. For example, it was assumed that feed supplements were of a consistent nutrient value, but research has shown that there is a wide variation in nutrient value between feed supplements and therefore the data for feed supplements was not an accurate representation of the actual supplements (Homes, 2002; Monaghan, 2008).

The level of detail describing the infrastructure for the production process was insufficient to allow the apportioning of capital assets on a per hectare basis. For the purposes of this research, it was assumed that the infrastructure required for dairy farming under Scenario One was similar to the capital structure under the national model (Saunders, 2007). This assumption took into account that the scale of farming was higher under Scenario One, which would potentially result in returns to scale in the use of capital assets with higher stock numbers and greater productivity per cow. Therefore, incorporating empirical data from the national model for capital inputs under Scenario One provided a conservative estimate of input levels per tonne of milk solids.

5.2.1.2.2 Scenarios Two and Three

The farm management regimes for Scenarios Two and Three were based on the FEMP which outlined the operational plan for the alternate management systems (Ryder Consulting, 2010). It was anticipated that this and other supporting documents would provide sufficient information to give a complete data set for the inventory template. However, neither the FEMP nor the supporting documents contained detailed input requirements for each alternative regime (Borrie, 2009; Engelbrecht, 2009; Ryder Consultants, 2009). Data were available on a per annum basis for expected pasture production levels, anticipated application rates of organic and inorganic nitrogen, and proposed rates of water irrigation. However, there was not sufficient information to allow for estimating the fuel consumption for pasture maintenance and harvesting, or the demand for electricity under the alternate regimes. The average use of electricity per cow for the region was available as an alternative estimate of electricity use but there was no way to validate the accuracy of using the current average figure to represent future production systems in the area (Pangborn, pers. comm., Doak, pers. comm.).

There was no detailed information on the proposed use of agrichemicals or the anticipated requirements for supplementary feeds, although under Scenario Two, the requirements for grazing off the farm during the winter months could be calculated on a per head basis if assumptions on the location of off farm grazing were incorporated into the analysis (Ryder Consulting, 2010).

The layout of the herd home was documented and the effluent management facilities were outlined, which provided relevant information for the Third Scenario (Mitchell, 2009). The level of detail describing the herd homes and the effluent facilities would allow for calculating the energy content of this infrastructure using the coefficient derived by Wells (2001).

There was no information provided on vehicular requirements for the alternate management regimes of conventional farming and herd farming, and there were no specifications for the fencing and water supply infrastructure which would be required for animal management.

5.2.1.2.2.1 Contingency Methods for Data Collection

As shown in Figure 3, alternative sources of input data were also investigated. Initially, open ended questions were directed to the Senior Policy Analyst during an interview seeking clarification as to what information was available from the MAF Pastoral Monitoring Programme (Doak, pers. comm.). Only aggregated data from the programme were available to preserve the confidentiality of information supplied by monitor farms and, further to this, there were no monitor farms within the Mackenzie area. Doak suggested one option was to use an existing farm in this area as a case study. However, there was no comparable industry data for the Mackenzie area, so it would be difficult to ascertain how representative a case study farm would be of conventional farming regimes in the Mackenzie Country.

During an interview with the Executive Director of the South Island Dairy Development Centre (SIDDC), it was reiterated that there were no available industry data for production regimes in the Mackenzie Country (Pellow, pers. com., 2010). Using production parameters from an existing dairy farm in the area was proposed as an alternative source for data sets, and it was suggested that the Dairy NZ representative in Oamaru would be the initial person to contact. Email and telephone contact was made with a dairy farmer in the Mackenzie Country as a follow up on this suggestion. The farmer was initially prepared to provide empirical data on inputs for his dairy farming systems, but confidentiality issues were of concern and the production information was not supplied. The farmer claimed that dairy farming in the Mackenzie Country area was a sensitive issue and that information supplied would not necessarily represent farming systems in the area.

Pellow emphasised that the pasture growth curves for the Mackenzie Country are distinctly different to pasture growth curves in South Canterbury, and transposing production parameters from South Canterbury to the Mackenzie Country would not provide an accurate representation of pasture growth. Variations in winter grazing strategies were also highlighted as crucial variables in dairy production systems, especially where there was a contrast in climatic conditions; and this aspect also limits the validity of transposing data sets from one area to another. There would also be variations in the productivity of cows between the areas where strategies for off-pasture wintering facilities influences the condition of the animals as well as the productivity of pastures (Pellow, pers.comm.)

SIDDC is an industry funded partnership supported by key organisations within the dairy industry including farmer cooperative such as Dairy NZ, Livestock Improvement Corporation, and Ravensdown, and also research institutions such as Lincoln University (Pellow, 2010). Consequently, as the Executive Director has broad access to industry knowledge, the conclusions taken from the interview included that representative data are not available for dairy production in the Mackenzie Country, and that transposing farm data from South Canterbury to dairy production systems in the Mackenzie Country may not support an accurate model for analysis.

Further industry information was obtained from an interview with a lecturer in Animal Sciences at Lincoln University who has written articles on the changing structure of land use in Canterbury, and who personally owns a dairy farm in South Canterbury (Pangborn, 2010b). His background supports a practical perspective on dairy farming and data collection, as well as providing an understanding of the impetus for land use change in Canterbury. The interview technique used open ended questioning to build on industry knowledge held by the researcher, as well as to ascertain how Pangborn viewed the practicality of obtaining credible data for use in the LCA model (Yin, 2003). Pangborn's opinion was that using specific farms in the Mackenzie Country as case studies would be the most credible method of obtaining complete data sets for analysis. However interpretation of results would require caveats stating that the raw data was not representative of the region or a specific farm management regime. The reasoning for this was that the range in diversity in dairy farm performance was influenced by farm management skills, the physical and climatic framework for each individual farm, and the financial constraints imposed on farm management choices, which are difficult to define (Pangborn, 2010b).

Pangborn (2010b) highlighted the trade off in research integrity between the completeness of the data sets required for scenario analysis under LCA, and how representative and reliable the data sets would be of the Mackenzie Country area (Ref. Table 2).

Interrogation of other industry information sources included the Sustainability Dairy Strategy Manager for the Fonterra Co-operative Group, Dairy NZ representatives from the Oamaru office and the research centre in Hamilton, the consultants who compiled the FEMP and supporting documentation (Aqualink, 2010; Engelbretch, 2010; Ryders Consulting, 2010), a director of the company which applied for the resource consent, the Ravensdown Fertilizer Company, and an individual dairy farmer who owns a dairy farm in South Canterbury. Attendance at the NZIAHS[11] Forum on "Where do we want our dairy industry to be in 20 years time?" also provided an overview of contextual changes in the dairy industry which were anticipated by industry leaders over the next two decades (NZIAHS, 03/09/2010). A common theme was the dearth of empirical data representative of dairy production systems within the Mackenzie Country. Although the Ravensdown representative was able to provide a fertilizer regime for an existing farm in the Mackenzie Country area; and a farmer could provide the parameters for an operational dairy enterprise in the area, confidentiality issues were problematic in using this information for comparative analytical studies (supporting transcripts available on request).

It was concluded that the integrity of data collection to support a LCA of dairy production systems under Scenarios Two and Three would be undermined by the absence of representative data, and subjectivity would be incorporated into the process of collecting available data by interviewing individuals (O'Leary, 2009; Yin, 2003). Subjectivity would introduce bias and unreliability in representation of the data and where comparative research is not available, verifying the authenticity of data sets was not possible (O'Leary, 2009; Yin, 2003). Consequently, simulated models to support Scenarios Two and Three would not provide valid representation for LCA and an analysis of these scenarios was not undertaken.

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[11] NZIAHS: New Zealand Institute of Agricultural & Horticultural Science Inc.

Chapter 6 Results and Interpretation

6.1 Stage 3: Impact Assessment

In the absence of credible data to support analysis of Scenarios Two and Three, impact assessment was limited to evaluating Scenario One. The cumulative primary energy content was calculated for the inputs quantified during the inventory analysis. This calculation was portrayed as the "Model" in Figure 4 where the primary energy content of each input was calculated using the conversion coefficients recorded in Table 6, based on the functional unit was one tonne of milk solids. The carbon emissions were also calculated using the emission coefficients listed in Table 6. The empirical analysis is summarised in Table 4.

Table 4 presents the quantity of primary energy required by the production process under Scenario One, to produce one tonne of milk solids. The primary energy embodied in the inputs is the total energy required from the cradle to the farm gate, and equates to 24,850 MJ per tonne of Milk Solids. The consequent carbon dioxide emissions from the production process have also been presented by input category and cumulatively amount to 2,144 Kg / t MS for every tonne of milk solids produced.

6.2 Stage 4: Interpretation

The results from the LCA of Scenario One indicate that indirect inputs account for approximately half of the primary energy requirements for producing one tonne of milk solids. Direct inputs including fuel and electricity use; contribute 42 percent to energy requirements, whereas only 7 percent of the energy total can be accredited to the capital infrastructure of the production system. Within these categories, the direct use of electricity accounts for 32 percent of the energy content and fertilizer applications amount to 45 percent of the total primary energy. The results from LCA point to the use of electricity and fertilizer as being the key components of the total energy requirements of the dairy production system.

Table 4: Energy use and Carbon Dioxide Emissions: Scenario One

Inputs		**Quantity per Kg MS**	**Energy use**	**CO2 Emissions**
Direct		(litre or KWh use/ MS per ha)	(MJ/Tonne MS)	(kg CO2/Tonne MS)
	Diesel (litres)	0.0411	1791	123.05
	Petrol (litres)	0.0150	600	40.22
	Oil (litres) Lubricants.	0.0004	18	0.65
	Electricity (KWh)	0.9689	7887	151.43
Indirect		(kg use /MS per ha)		
	Fertiliser:			
	Nitrogen (Kg)	0.1379	8966	448.28
	Phosphorus (Kg)	0.0314	471	28.23
	Potassium (Kg)	0.0000	0	0.00
	Sulphur (kg)	0.0381	191	11.44
	Dolomite	0.0000	0	0.00
	Lime (Kg)	2.5165	1510	1087.12
	Agr-chemicals			
	Fungicide (kg ai)	0.0007	228	13.69
	Acids and Alkalis (kg ai)	0.0029	354	21.21
	Animal Remedies (kg)	0.0005	55	3.31
	Other Chemicals (kg)	0.0010	117	7.02
	Seed (kg)	0.0011	0	0.00
	Brought in animal feed supplements	0.0000		
	Forage & Fodder (tonne of dry matter)	0.2976	417	24.17
	Cereals/ concentrate (tonne of dry matter)	0.0637	145	8.45
	Grazing-off (Ha)	0.0001	259	15.53
	Aggregate (Kg)	0.8201	82	5.64
Capital				
	Farm Buildings (m3)			
	Dairy Shed (cups)	0.0000	527	52.7
	Other Farm Buildings (m3)	0.0002	185	18.50
	Self propelled vehicles (kg)	0.0035	231	20.77
	Machinery (Kg)	0.0041	211	21.11
	Fences (m)	0.0030	169	16.9
	Races (m)	0.0009	110	7.7
	Stock water supply (ha)	0.0000	85	5.95
	Irrigation (ha)	0.0000	120	3.6
	Effluent disposal system (m3)	0.0000	123	7.626
	Total Production		24,850	2,144
	Yield (kg Milk Solids)	1334		

Research conducted at the national level also showed that electricity and fertilizer were key contributors to the energy requirements under an average dairy production system at 24 percent and 36 percent respectively (Saunders, 2007). The use of fuel at 17 percent of the total, was also a key contributor to total energy requirements. However in comparison, Scenario One results showed that the more intensive production system required proportionally more embodied energy from electricity and fertilizer inputs, and less energy from fuel inputs, than under a national average dairy system (Saunders, 2007). This variance reflects the change in weighting of the inputs in the production process where typically, electricity is used to operate the dairy parlour and for irrigating water. On average, an irrigated dairy farm uses 73 percent of electricity inputs for irrigation and the balance is used in the dairy shed (EECA, 2010). Fertilizers inputs which are used to support pasture production are derived from fossil-fuels and accordingly have relatively high primary energy content (PCE, 2004).

Further comparison of Scenario One with the National Model indicated that where a more intensive farming regime uses higher levels of irrigation and fertilizer, not only does the proportional contributions of inputs change, but the total primary energy requirement for producing one tonne of milk solids also increases. This increase implies that the more fertilizer and water intensive the regime, the higher the levels of primary energy required in producing the same amount of milk solids. The results showed that required primary energy under Scenario One amounted to 24,850 MJ / tonne MS whereas 22,074 MJ / tonne MS was required under the National Model, an increase of 2,776 MJ / tonne MS (Saunders, 2007).

The carbon dioxide emissions associated with the production process under Scenario One were significantly higher than the emissions associated with producing one tonne of milk solids under the National Model (Saunders, 2007). These emissions were 2,144 Kg CO_2 / Tonne MS and 1246.3 Kg CO_2 / Tonne MS respectively.

6.3 Limitations of the Research

However, where the validity of direct comparison between the results of the two analyses depends on how similar the boundaries are in definition, and on the degree of consistency between the methods of data collection and analysis, dissimilarity between Scenario One and the National Model required interpreting results within limitations (Berlin, 2003). The inconsistencies between the boundary definitions and in the integrity of data sets for the two models were identified as follows:

- The time frame for the national evaluation was 2001 whereas the data supporting the analysis for Scenario One was related to 2009. The data integrity and methods of data collection by the MAF Monitoring Programme have not been verified as being consistent under the two time frames, and although the same methodology has been adopted for both models, inconsistency could have occurred in the collation of the secondary data sets during the different periods.

- The National Model is representative of the New Zealand Dairy industry whereas Scenario One represents farming systems in the Canterbury region. Where the geographical boundaries differ, so will the physical and infrastructural contexts of the analyses differ. Uncertainty exists as to how variations in the physical and infrastructural characteristics of the different geographical boundaries influence the primary energy requirements of the production systems.

- The definition of the technological and infrastructural framework of the production systems is not precise enough under the two models to allow all intrinsic differences between the frameworks to be identified. Where unidentified differences could potentially contribute to the variations in energy requirement for the alternative production systems, the results from the LCA could misrepresent the contribution of specific inputs to the energy total. For example, energy efficiencies which may have occurred in the manufacture and transportation of fertilizers over the past decade have not been considered in the comparison. If this was the case then the estimated contribution of fertilizers to the total energy requirement may have been over estimated.

- The data set supporting analysis of Scenario One was incomplete where in particular, the data defining capital inputs for the model were not available. The integrity of the data set was compromised where data for capital inputs from the national model were incorporated into the analysis as a conservative estimate of the infrastructure.

- Further to this, subjectivity was introduced into the analysis of Scenario One where financial expenses of inputs were converted to physical equivalents. Subjective assumptions based on the triangulation of secondary information, attributed values to inputs to enable the conversion. However, validation of these values has not been possible within the limited resources available for the research project. The assumptions made in converting the data format have been detailed in the appendix under Table 8.

- Limited research resources also constrained assessing how closely Scenario One represents the production systems of a representative dairy farm in the Canterbury region. Partial verification has been attempted using an alternative secondary source of input costs (Pangborn, 2010a). However, this source also relies on the MAF data base to an extent, and therefore does not provide independent verification of the accuracy of input data.

Although the framework for analysing Scenario One is consistent with the framework adopted for analysing energy requirement for dairy production systems at the national scale, consistency in boundary definition and data collection was not possible. Validation of the entire LCA model using empirical testing was not feasible under the resource constraints of this research project. However, in an attempt to mitigate these limitations of uncertainty, the process of model development including the supporting assumptions, has been documented in full. Interpreting the results has been undertaken within the context of these limitations.

Chapter 7 Discussion, Recommendations and Conclusions

7.1 Discussion

The structure of the dairy industry has changed over the past decade where intensification of dairy production systems and the expansion of the land area used for dairying were the main components of this structural change. Industry leaders anticipate strong growth in dairy production over the next twenty years, and they expect that this growth in production will be supported by continued intensification of production and expansion of the land area under dairying (NZIAHS, 2010). In the absence of significant technological advances in management practices, fertilizer applications and water irrigation will continue to underpin this intensification in dairy production.

However, previous analysis has indicated that the primary energy requirements for producing one tonne of milk solids increases as the intensity of fertilizer and water applications increase, and further intensification of production systems could be interpreted in export markets as New Zealand dairy products becoming more energy intensive. This could be problematic for dairy exports where the scrutiny of environmental impacts of production processes is increasing in export markets and where purchases choices are based on this scrutiny.

Further to this, export markets are becoming increasingly reliant on information systems, such as eco-labels, to serve this environmental scrutiny of products; and at present New Zealand only has environmental indicators which measure the primary energy requirements of an average dairy production system. These macro level indicators do not account for regional variation, nor do they provide an indication of the changes in energy requirements which are occurring at the margin of structural change within the industry.

For these reasons, where there is greater disparity in management regimes between regions, indicators derived from national averages may no longer be the most credible way of assessing the energy requirements of dairy production at the farm scale. The provision of relevant farm scale indicators could become an increasing requirement for exported dairy products, to meet consumer demands for credible information on the environmental impacts of dairy production, especially where it is recognized there is greater disparity between regions.

In this research, LCA provided an appropriate framework for measuring the energy requirements of the alternative management regimes at the farm scale. However, the lack of representative data prevented valid comparison of the environmental indicators between the alternative management regimes chosen to represent structural change within the industry. There was only sufficient data to support the evaluation of energy requirements for a representative farm for the Canterbury region.

Comparison of the Canterbury farming system with a typical farm for the dairy industry indicated that the different combinations of technology, infrastructure and levels of inputs alters the primary energy requirements for producing one tonne of milk solids. These results indicated that efficiency in energy use is regressing under more intensive management regimes where fertilizer and water applications are the cornerstones of intensification. Although the current format of industry knowledge precluded quantifying all the crucial variables and linkages within the specific dairy production system without incorporating subjectivity, and where further investigation is necessary to substantiate this claim, the implication that energy efficiency is regressing under more intensive regimes does justify discussing the consequences of the proposed management regimes in the Mackenzie Country.

Scenarios Two and Three represent the changes in management regimes at the margin of structural change in the industry where Scenario Two represented expansion into non-dairying areas, and Scenario Three represented intensification in animal husbandry practices. Qualitative comparison of the management regimes for the three scenarios highlighted distinct differences in management practices. The scale of farming was greater under Scenarios Two and Three where the effective areas were 60 percent greater than the Canterbury farm model. Fertilizer and water application levels under Scenarios Two and Three supported higher annual pasture growth rates than in Canterbury, and the wintering strategies for stock were different to the Scenario for Canterbury. The infrastructure required for housing the cattle under Scenario Three was distinctly different to Scenarios One and Two.

The differences in management practices would have direct implications for the level of use of fertilizer and electricity. The level of fertilizer applications in the Mackenzie Country scenarios would be have to be at least equivalent to the rate of application of the Canterbury model to support the higher pasture production levels (Engelbrecht, 2010). Although under Scenario Three, effluent used for organic nitrogen applications would lower the dependence on inorganic fertilizers which have higher primary energy content than organic fertilizers, and subsequently energy savings in fertilizer inputs could be realised under this scenario. Less energy could be required in applying fertilizer per hectare where there are efficiency gains through the returns to scale of the farming systems. However, the primary energy content of inorganic fertilizer inputs is more a function of being fossil-fuel based rather than the energy required in applying fertilizer, and therefore energy savings from returns to scale in application would not be significant as the levels of application.

The proposed irrigation regimes under the Mackenzie Country scenarios use centre pivot irrigators to irrigate the entire effective area of the farm inferring that the electricity required for irrigation per hectare would also be at least equivalent to electricity requirements under the Canterbury Scenario. Scenario Three would require added electricity inputs to maintain the herd homes, and therefore the contribution to primary energy per tonne of milk solids from electricity would be higher than under Scenarios One and Two.

The fuel component under Scenario Three could be proportionally higher than the two other scenarios. The mechanical harvesting of the pasture would require fuel to operate harvesters and cartage vehicles on a regular basis, and where the fuel is derived from fossil resources, the increased use of fuel would impact on the primary energy content of dairy production.

Although empirical analysis of Scenarios Two and Three was not undertaken, comparison of the management practices with those of the Canterbury model suggests that the energy requirements for the production processes would be at least at the level of the production processes in Canterbury. The level of use of the key contributors of electricity and fertilizer would be similar to Canterbury under Scenario Two; and there would potentially be a trade off between lowering the primary energy content through the use of organic nitrogen and raising the energy requirements through increased fuel for mechanical harvesting under Scenario Three.

Drawing on these conjectures suggests that identifying the interconnections between different farming practices and quantifying the differing levels of inputs for Scenarios Two and Three would support the claim that efficiency in energy use is regressing under more intensive farm management regimes. Consequently, where it is anticipated that industry growth will be supported by further intensification and expansion, political and commercial concerns associated with apparent negative trends in the energy efficiency of New Zealand dairy production will be valid. Providing indicators of energy efficiency for production systems at the farm scale would quantify the extent to which intensification of production systems is contributing to increased content of embodied energy in dairy products sold in export markets, and therefore support policy initiatives by the public and private sectors to manage the “clean and green” promotional strategy of the New Zealand dairy industry.

Although the absence of credible data sets may preclude developing indicators of energy efficiency in the short term, this research has shown that to an extent, empirical data is available which represents alternative dairy farming systems. It is the completeness and the format of the data which is problematic in its use for deriving environmental indicators.

Where research into the environmental impacts associated with dairy production has been conducted, there appears to be no systematic development of data bases to support evaluating the efficiency of energy use under more intensive management regimes at the farm scale (Barber 2005; Dairy NZ, 2009; Doak, 2010; Pellow, 2010; Saunders et al., 2006). Although models have been developed to assess how changes in farm management practices can mitigate GHG emissions from the dairy production process, and a pilot study has been launched as a joint initiative from Fonterra, the Energy Efficiency and Conservation Authority and MAF, to identify where energy efficiency can be gained in production systems, there is an absence of complete data sets which would support developing valid and meaningful indicators of energy requirements for producing one tonne of milk solids (Smeaton, 2010; Energy Efficiency and Conservation Authority, 2010).

Developing credible data sets would require integrating and collating farm scale information from service industries such as fertilizer cooperatives, agri-chemical companies, utility companies and companies who supply farm infrastructure, into an industry monitoring programme which is specifically designed to measure primary energy requirements under different farm management regimes. It would therefore also require a collaborative effort between industry participants to overcome barriers which could prevent the sharing of industry knowledge (Cairns, 1991).

7.2 Recommendations

Drawing on the findings of this research, it is recommended that scoping is undertaken in export markets as a means to define an indicator which is relevant to consumers of dairy products; as well as a means to provide the criteria for a monitoring programme to support such an indicator, by determining:

- What indicators are being used to measure the primary energy and / or the associated carbon dioxide emissions of dairy products.
- What are the specifications of the indicators which make them valid and meaningful to the market.
- What organisations and / or retail chains are coordinating the development and use of the relevant indicators.

It is also recommended that a monitoring programme is developed for the dairy industry to develop a data base to support an indicator of primary energy and / carbon emissions for dairy products at the farm scale where the responsibility for managing and reviewing the programme is with either:

- A government organisation such as MAF where the advantages would include already having substantial industry knowledge and contacts; and issues of confidentiality could be managed within the ethical requirements already in place within MAF.
- Or: an industry institution such as Dairy NZ which has a wealth of knowledge on dairy industry initiatives but issues of transparency in data management could be of concern to stakeholders.
- Or: a University such as Lincoln University or Massey University who also have a wealth of knowledge on dairy industry initiatives and where transparency of data base management could be provided; but where confidentiality could be considered an issue if it is perceived that the data base is used for other research within the university.
- Or: a Crown Research Institute such as Landcare Research which has the organisational framework to manage a monitoring programme and which is a body considered to be independent of commercial interests in the dairy industry.

7.3 Conclusions

Empirical comparison of intensive farming practices with a typical dairy farm suggests that the total quantity of primary energy required to produce one tonne of milk solids is increasing as the production processes intensify within the New Zealand dairy industry. Fertilizer applications and the use of electricity are the key contributors to the energy requirements of dairy products and it is anticipated that these inputs will underpin future growth in the dairy industry.

Where there is increasing scrutiny in export markets of the environmental impacts of dairy production processes, there is also an increasing reliance on information systems by consumers to assess these environmental impacts when purchasing dairy products. Developing a monitoring programme to measure the energy required in dairy farming systems at the farm scale and the associated carbon dioxide emissions, would provide credible indicators to enable the dairy industry to participate in the eco-labelling information systems in export markets, and would support policy initiatives to manage the “clean green” promotional strategy of the dairy industry.

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Appendix A

Table 5: Inventory Template

Source: Saunders (2006)

Direct		Diesel (litres)
		Petrol (litres)
		Oil (litres) Lubricants.
		Electricity (KWh)
Indirect	Fertiliser:	Nitrogen (Kg)
		Phosphorus (Kg)
		Potassium (Kg)
		Sulphur (kg)
		Dolomite
		Lime (Kg)
	Agr-chemicals	Herbicide (kg ai) Para., Diquat, Glyphosate
		Herbicide (kg ai) general
		Fungicide (kg ai)
		Insecticide (kg ai)
		Plant Growth Regulator (kg ai)
		Acids and Alkalis (kg ai)
		Animal Supplements (e.g. Magnesium, zinc)(kg)
		Animal Remedies (e.g. Drench, bloat aids)(kg)
		Other Chemicals (kg)
	Seed (kg)	
	Brought in animal feed supplements	Grass silage (tonne of dry matter)
		Maize silage (tonne of dry matter)
		Hay (tonne of dry matter)
		Cereals/ concentrate (tonne of dry matter)
	Grazing-off (Ha)	
	Aggregate (Kg)	
Capital	Farm Buildings (m^3)	Dairy Shed (cups)
		Other Farm Buildings (m^3)
	Self propelled vehicles (kg)	Tractors (kg)
		Heavy Trucks (kg)
		Light Trucks & Utilities (kg)
		Motor Bikes (kg)
		Machinery (Kg)
	Fences (m)	
	Races (m)	
	Stock water supply (ha)	
	Irrigation (ha)	Border Strip (ha)
		Spray Irrigation (ha)
	Drainage (m or ha)	

Appendix B

Source: Saunders (2007)

Table 6: Energy and Carbon Dioxide Coefficients

Inputs

Direct		**Energy use**	**Carbon Dioxide emission**
		(MJ / Litre)	(kg CO2 / MJ)
	Diesel (litres)	43.6	0.0687
	Petrol (litres)	39.9	0.0670
	Oil (litres) Lubricants.	47.4	0.0359
	Electricity (KWh)	8.14	0.0192
		Energy use	**Carbon Dioxide emission**
Indirect		(MJ / Kg)	(kg CO2 / MJ)
	Fertiliser:		
	Nitrogen (Kg)	65	0.05
	Phosphorus (Kg)	15	0.06
	Potassium (Kg)	10	0.06
	Sulphur (kg)	5	0.06
	Lime (Kg)	0.6	0.72
	Agr-chemicals		
	Herbicide (kg ai) Para., Diquat, Glyphosate	550	0.06
	Herbicide (kg ai) general	310	0.06
	Fungicide (kg ai)	310	0.06
	Insecticide (kg ai)	315	0.06
	Plant Growth Regulator (kg ai)	175	0.06
	Acids and Alkalies (kg ai)	120	0.06
	Animal Remedies (e.g. Drench, bloat aids)(kg)	120	0.06
	Other Chemicals (kg)	120	0.06
	Seed (kg)		
	Brought in animal feed supplements		
	Grass silage (tonne of dry matter)	1.4	0.058
	Maize silage (tonne of dry matter)	1.65	0.058
	Hay (tonne of dry matter)		
	Cereals/ concentrate (tonne of dry matter)	2.3	0.0584
	Grazing-off (Ha)	1726	0.06
	Aggregate (Kg)	0.1001	0.0687

Table 6 contd.

Capital			
Farm Buildings (m2)			
Dairy Shed (cups)	*		0.1
Other Farm Buildings (m2)	**		0.1
Self propelled vehicles (kg)		65.5	0.09
Tractors (kg)		65.5	0.09
Heavy Trucks (kg)		65.5	0.09
Light Trucks & Utilities (kg)		65.5	0.09
Motor Bikes (kg)		65.5	0.09
Machinery (Kg)		51.2	0.1
Fences (m)			0.1
Races (m)			0.07
Stock water supply (ha)			0.07
Irrigation (ha)			0.03
Effluent disposal system (m3)			0.062

* = GJ=24.2*sets+293
** = 590 MJ/m2

Appendix C

Table 7: Fertilizer Regime for Scenario One.

Type	Quantity
Superphosphate	94.5 tonnes
Urea	84.0 tonnes
Lime	705.0 tonnes

Appendix D

Table 8: **Assumptions for Converting Financial Input Data to Physical Equivalents**

Scenario One: Canterbury Model

Input data taken from the MAF Pastoral Monitoring Programme 2009 (MAF, 2009).

1. **Fuel Consumption:**

Fuel expenses for Year Ending June 2009: $20,400.

Proportional use of fuel for a typical dairy farm:

Diesel:	57.3 litres per hectare	(71% of total fuel)
Petrol:	22.9 litres per hectare	(28% of total fuel)
Oil:	0.9 litres per hectare	(1% of total fuel)

(Source: Saunders et al. 2006)

Where the price of fuel was:

Diesel:	$1.10/ litre
Petrol:	$1.67 /litre
Oil:	$5.56 /litre

(Source: Farm Budget Manual 2010, pages B140 and B142, (Pangborn, 2010a)

Calculating the use of Fuel per effective hectare:

(((% expense of Total Fuel * Total Farm Fuel Expenses)/ ($/litre)) / Effective Hectares)

Diesel: (((0.621*$20,400)/$1.10)/210) = 54.84 L/ ha

Petrol: (((0.345*$20,400)/$1.67)/210) = 20.07 L/ ha

Oil: (((0.029*$20,400)/($5.56)/210) = 0.507 L/ ha

2. **Electricity Consumption**:

Electricity expenses for Year Ending June 2009: $60,000

Electricity prices for the Canterbury region were 22c/KWh + 79c /day for both the Orion Network and Meridian Utilities Companies (Source: Farm Budget Manual 2010, page B72) (Pangborn, 2010a)

Daily charge: $0.79 *365 days = $288

Calculated approximate usage per hectare:

(((Total Farm-∑daily charge)/$ per KWh)/effective hectares)

= ((60,000-288)/0.22)/210) = 1292. 47 KWh /ha

Triangulation of this calculation:

National average cost of electricity per cow = $51 / cow

Canterbury average cost of electricity per cow = $ 85 / cow

Source: Farm Budget Manual 2010, page B69 (Pangborn, 2010a)

Electricity costs per cow are 66% higher in Canterbury compared with the national average and where the average stocking rate is 22% higher in Canterbury, and assuming the cost per KWh is similar, then electricity usage per hectare could be expected to be double that of the national average. (1.66*1.22= 202) The electricity usage per hectare under the national model was 556 KWh which is just under half the 1292 KWh / ha which has been calculated as the physical equivalent of $60,000 for Scenario One. Therefore it was this figure was realistic.

3. **Fertilizer:**

The fertilizer regime for the Canterbury Model was supplied by MAF (Doak, 2010)

Superphosphate:	94.5 tonnes
Urea:	84.0 tonnes
Lime:	705.0 tonnes

The fertilizer types and analysis by chemical composition was also supplied:

Superphosphate: 9.3% Phosphorous equates to 8.788 tonne

11.3% Sulphur equates to 10.678 tonne

Urea: 46.0% Nitrogen equates to 38.64 tonne

Converted to Kg per hectare: (210 ha)

Phosphorous: ((8.788 /210)*1000) = 41.85 Kg / ha
Sulphur: ((10.678/210)*1000) = 50.85 Kg /ha
Urea: ((38.64/210)*1000) = 184 Kg /ha
Lime: ((705/210)*1000) = 3,357 Kg /ha

4. **Agrichemicals:**

Fungicides: Weed and Pest Control: Whole Farm Expenditure = $6,800
With reference to the Farm Budget Manual 2010, page B110,
Average cost per stock unit: Nationally and for the Canterbury region: $10/ cow.
And the average usage for the national model was 0.8 Kg ai / ha where the stocking rate was 2.77 cows per hectare, then this equates to 0.289 Kg ai per cow.
Where Canterbury has a stocking rate of 3.4 cows per hectare, the usage of fungicides would equate to (0.289 *3.4) = 0.982 Kg ai / ha

Acids and Alkalis

Canterbury Dairy shed expenses $13,700 which does not include animal health or electricity.
The national average for dairy shed expenses = $22 / cow
The Canterbury average for dairy shed expenses = $19 / cow

Source: Farm Budget Manual 2010, page B28. (Pangborn, 2010a)

The average national usage of per hectare of Acids and Alkalis was 3.2 Kg ai / ha which with a stocking rate of 2.77 cows per hectares this equates to 1.155 Kg per cow. And where the expenses for 2009 per cow were ($13,770/705) = $19 /cow in Canterbury compared with the national average of $22 / cow, and assuming that the prices are similar nationwide, then the use per cow in Canterbury would be ((19/22)* 1.155) = 0.864 Kg ai per cow. Where the stocking rate in Canterbury was 3.4 cows per hectare, this equates to 3.93 Kg ai / ha.

Animal Remedies:

Expenses for the Canterbury model: $57,500
National average costs for animal health: $73 / cow
Canterbury average cost for animal health: $82 /cow

Source: Farm Budget Manual 2010, page B9. (Pangborn, 2010a)

Assuming that the products cost the same nationally, Canterbury used 1.123 times more product per cow, and where the national average usage was 0.5 Kg ai per hectare with 2.77 cows per hectare, the usage per cow was 0.1805 Kg ai / cow. In Canterbury where the stocking rate was 3.4 cows per hectare, the usage per hectare was 0.6137 Kg ai / ha.

Other Chemicals:

There was no available information on the financial expenses or physical quantities for "Other Chemicals". The figure for the national average of 1.3 Kg ai per hectares was assumed for the Canterbury model. There was no validation of this figure.

5. **Seeds:**

The usage of seeds in the Canterbury model was prorated using the differential between the average national costs for regrassing and the average costs for Canterbury. It was assumed that the processes involved in regrassing would be similar and the differential in actual expenditure would be a reflection of different pasture management for regrassing.

The national costs per effective hectare were: $67.29 ($7,200/107)
The Canterbury costs per effective hectare were: $73.33 ($15,400/ 210)
Source: (MAF, Pastoral Monitoring Programme, 2009)

Canterbury spent 1.09 more on regrassing than the national average and where the national model used 1.3 Kg of seed per hectare, this was prorated up by 1.09 to 1.42 Kg /ha.

6. **Brought in Animal Supplements:**

Farm expenses for supplementary feed for the Canterbury model included $120,600 for hay and silage, $152,300 for grazing, and $121,300 for "other" supplements. This financial information was difficult to differentiate into physical volumes due to the aggregated nature of the data set as well as the variability in the quality and type of supplementary feed. For example, silage can be bought in a variety of bale sizes and the quality of the silage can vary significantly depending on the conditions of harvest and subsequent storage (Homes, 2002). Feed prices were extremely volatile during the 2009 year due to changeable weather conditions and alternative feed supply (MAF, 2010). Small bales of meadow hay were advertised at $15 per bale at the beginning of June, whereas a month later, the advertised price was $9 per bale (The Press, 06/06/2010; 04/07/2010). Wide ranges in the type and value of supplementary feed are recorded in the Farm Budget Manual 2010 such as Palm Kernel Blend Pellets varied from $429 to $514 per tonne (Pangborn, 2010a: B38). Consequently, there was no credible approach to defining values for supplementary feed to calculate the physical equivalent of the financial data set.

The national average for expenditure on supplementary feed was $1551 per hectare whereas the expenditure under the Canterbury model was $1877 per hectare, an increase of 20 percent. Considering this higher expenditure under the Canterbury model, the values from the national model have been used for Scenario Three as a conservative estimate of the quantities of supplementary feed required. Estimation of the primary energy and subsequent carbon emissions for these inputs will therefore, also be on the conservative side.

Estimates used in Scenario Three for “Brought in animal feed supplements”

Grass Silage	397 tonne DM
Cereals / concentrates	85 tonne DM
Grazing –off	0.2 ha

7. Capital

The expenses covering the use of capital inputs were not presented in a form which allowed disaggregation and conversion to physical equivalents. The level of detail describing the infrastructure for the production process was insufficient to allow apportioning the use per hectare, and therefore it was not possible to identify the cost of operating the assets on a per hectare basis. For the purposes of this research, it was assumed that the infrastructure required for dairy farming under Scenario One was similar to the capital structure under the national model. This assumption took into account:

1. That farming in Canterbury is on a larger scale than the national average, and
2. That due to the potentially greater efficiency of using farm infrastructure with higher stock numbers, the energy requirements per tonne of milk solids could be lower under Scenario One than the nation average. (*Returns to scale*)

Using the empirical data set from the National Model for capital inputs under Scenario One provides an estimate of energy requirements which was considered to be a conservative estimate of energy requirements for Scenario One; and provides data for this model which is representative of the capital asset structure of the dairy industry. Unfortunately, incorporating empirical data into the analysis which represents the average of the industry will preclude identifying any change in energy requirements or carbon dioxide emissions which would be directly attributed to variation in capital asset structure under Scenario One. Research results were interpreted within the limitations of an incomplete data set where the assumptions made in using this data compromised the accuracy of the model mimicking the Canterbury production system.