Agricultural Greenhouse Gas Emissions:

Costs Associated with Farm Level Mitigation

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Antony Raymond Wolken
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Abstract

Agricultural greenhouse gas emissions within New Zealand account for 48 percent of all national greenhouse gas emissions. With the introduction of the emissions trading scheme farmers will soon be liable for their emissions, introducing additional physical constraints and financial costs. Farmers that still operate within the sector will have two options to meet emissions targets; to purchase carbon credits from the open market, or mitigate farm level emissions at added costs to the farmer. This study examines the latter case of assessing farm level options for mitigating greenhouse gas emissions, and quantifying the physical and financial costs associated with mitigation strategies. Results show that, based on the assumptions in the study, there are available options for dairy farmers to profitably meet Kyoto protocol emissions targets. Sheep and beef farmers can increase profit, but cannot meet Kyoto protocol emissions targets, through examined scenarios.

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Table of Contents

List of Tables

List of Figures

1 Introduction

As public awareness of climate change gathers prominence, policymakers are pressured to design environmental policies that limit agriculture‟s effect on the environment, whilst maintaining productivity and profitability within the sector. Along with the clean streams accord, farmers will be responsible for greenhouse gas emissions emitted by ruminant animals. The emissions trading scheme (ETS) is designed to make farmers accountable for emissions at the farm level, although the details of the scheme have not yet been finalised. International agreements to reduce greenhouse gas emissions for which New Zealand is a member include the Kyoto Protocol, signed by New Zealand in May 1998.

New Zealand is dependent on agriculture for a large proportion of its income, directly and indirectly. These land based activities are susceptible to climate change, both environmentally and economically. In percentage terms agriculture accounts for 10 percent of GDP and over 50 percent of total exports (Leslie, Aspin, & Clark, 2007). Therefore, any policy that affects agriculture will affect the country as a whole and must be correctly designed to achieve its desired goals and objectives.

A large reliance on agriculture, for income, creates a unique greenhouse gas profile compared to other trading partners, as a large proportion of our electricity needs are met through the use of renewable hydro energy sources. Carbon dioxide is the major greenhouse gas for international counterparts, which is emitted through power generation, industrial processes, and transport. However, New Zealand is unique in that agriculture is accountable for 48 percent of total national emissions, with approximately a third of national emissions coming directly from ruminant animals. Nitrous oxide emissions arising from the microbial breakdown of animal excrement and faeces are attributable for a further sixth of our national emissions (Leslie, et al., 2007). New Zealand has Kyoto protocol obligations to reduce emissions to 1990 levels. From 1990 to 2006 agricultural emissions have increased 15.9 percent to 37.7 Mt, although agricultural emissions have declined as a proportion of total national emissions (Ministry for the Environment, 2006). The increase can be accounted for by three compounding factors. Firstly, the amount of output from each animal has increased dramatically as farming became more intensive and productive. The result is animals consume more forage and energy, creating more methane (CH_4) emissions per animal along with more excretion leading to greater nitrous oxide (N_2O) emissions. Secondly, inorganic nitrogen fertiliser use has increased substantially by 297,000 tons since 1990, to support greater farming intensity and productivity. With the increasing global population"s need for meat and dairy products, the past global trend is likely to continue into the future. Thirdly, the number of dairy cows has increased from 2.4 million in 1990/91 to 4.0 million in 2007/08, a 66.7 percent increase in 17 years (DairyNZ, 2008c).

A distinction must be made surrounding total emissions and emissions per unit of output. The past trend has been for total emissions to increase over 1990 to 2006 (in New Zealand they rose 15.9 percent over these 16 years), but the emissions per unit of output has been declining since 1990. Leslie, et al. (2007) note that methane emissions have increased by 70 percent for the dairy sector since 1990, but emissions per stock unit have declined by 17.7 percent. This can be attributable to greater productivity per animal as marginal output has increased more than the marginal increase in emissions. For the sheep and beef industry, total emissions have fallen 18 percent since 1990 as a result of greater productivity combined with fewer animals farmed. The quantity of output produced within the industry has increased, despite reduced animal numbers.

New Zealand calculates its emissions profile according to the revised 1996 intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 1997). A tier-2 approach is taken due to the importance of agriculture within New Zealand, and the exceptional level of data the country has on agricultural greenhouse gas reporting. This methodology can be used at the individual farm level through the use of the OVERSEER Nutrient Budgets model, which uses the national methodology for calculating methane emissions and extends the national method for calculating nitrous oxide emissions.

The OVERSEER Nutrient Budgets model is a farm-scale nutrient reporting tool that is used extensively throughout New Zealand by farmers, farm consultants, and fertiliser representatives (Wheeler et al. 2006). Nutrients calculated and reported on within the model are: nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, and sodium. The model is increasingly being used to meet regional council resource management laws which limit the amount of nitrogen and phosphorus losses into waterways. Furthermore, to meet Fonterra"s Clean Streams Accord farmers are required to produce a nutrients budget. Fonterra farmers supply over 90 percent of national milk production to the co-operative. The model attempts to achieve maximum production while reducing nutrient losses to water. OVERSEER has had a recent extension, as it can estimate on-farm greenhouse gas emissions using the same variables. This enables New Zealand farmers to easily obtain reports on their emissions, providing them with the information to target and mitigate emissions. It has been postulated that on-farm reporting of greenhouse gas emissions will be required as part of the ETS.

There are many different options which have been investigated within the literature to reduce agricultural greenhouse gas emissions. As nitrous oxide is primarily formed by microorganisms, its rate of production is controlled by variables that influence the growth of microorganisms in the soil; for example temperature, pH, substrate and water content. There are two microbial soil processes which create nitrous oxide; nitrification, and denitrification. Since two microbial processes that have two different environmental requirements are involved, nitrification and denitrification, the production of N_2O depends on conditions that vary in space and time. Field measurements of N_2O generally indicate soil conditions that are consistent with denitrification suggesting that denitrification is the main source of N_2O emissions for intensive agriculture. However, this is often an essential part of intensive farming for denitrification to convert nitrogen inputs from urine, urea and ammonium based fertilisers.

The options to reduce nitrous oxide emissions generally fall into the following three categories: reduce the total amount of excreta nitrogen returned to pasture; increase the nitrogen use efficiency of excreta and/or fertilizer; and avoid soil conditions that favour N_2O emissions. The most effective option for intensive farming is to reduce fertiliser usage along with a slight reduction in animal numbers. This is the most accessible mitigation option available to farmers as there are no barriers to entry. Alongside reduced fertiliser use, farmers can keep production levels constant through the purchase of additional feed supplements.

However, there are some factors that farmers cannot control. Saturated soils from a heavy and sudden downpour will cause nitrous oxide emissions to spike temporarily. If the soil holds the water (i.e. does not drain adequately) and becomes waterlogged, the "soil will denitrify more than well drained soils, while improved drainage can reduce total denitrification losses" (de Klein & Eckard, 2008, p.16). Furthermore there is a risk of leaching if soils reach a certain level of saturation.

Methanogens, which cause methane emissions, perform the beneficial task of removing hydrogen from the rumen. This allows for reduced cofactors to be re-oxidised and recycled, enhancing the breakdown and fermentation of plant material. Unfortunately this process converts the excess hydrogen with carbon to create methane, a gas that has a global warming potential of 25 over 100 years. This means that one methane molecule is equivalent to 25 carbon dioxide molecules, in terms of global warming effects.

Farmers have been concerned about methane emissions since the seminal paper published by Blaxter & Clapperton (1965). However, they were concerned with reducing methane emissions from an efficiency standpoint. Methane emissions represent lost energy from the ruminant animal, where the greater the efficiency of the animal the lower will be the resultant methane emissions. Only recently has research redirected mitigating methane emissions with the aim of reducing greenhouse gas emissions.

There have been numerous suggestions to reduce methane emissions from grazing livestock. The specific measures fall into the following five general categories: farm management to directly reduce emissions, and to increase efficiency, manipulation of the ruminal microbial ecosystem, anti-methanogenic feed additives, and genomics.

The most promising options available for New Zealand farmers include changing feed intake and composition, to greater use of high concentrate grains. High concentrate feeds such as maize grain have a higher energy content and digestibility compared to pasture. Farmers may face supply side barriers to increasing the use of high concentrate grains.

Feed additives developed by scientists can shift hydrogen flows towards other alternative electron acceptors such as propionate, reducing generation of methane within the rumen. However, a significant boundary to mitigation is that the rumen inherently reverts back to methane production even after the imposition of alternative electron acceptors. Therefore, a multifaceted approach to methane mitigation involving several strategies may be required to make meaningful greenhouse gas emission reductions from ruminants.

Furthermore, it is important to note that not one feed additive is currently used with the sole purpose of mitigating methane emissions, despite extensive research and development. The main problems are that the additives are toxic to the animal, toxic to the rumen micro flora and therefore reduce feed consumption, have short term effects because the rumen adapts, are volatile and difficult to administer, are expensive, or would fail to meet consumer product acceptance (O'Hara, Freney, & Ulyatt, 2003).

Genomics has focussed on a variety of methods to reduce the amount of methane produced by ruminants. Research has begun to help understand how methanogens adapt which allows them to grow and persist in the rumen. The Pastoral Greenhouse Gas Research Consortium (PGGRC) is undertaking high level research to sequence the genome of a prominent methanogen in New Zealand agriculture. Approximately half of the genes identified within the genome have been identified with no known associated function. Determining the function of these new genes will assist in defining the role of genetics in the production of methane, and help identify new measures to control emissions from ruminants (Attwood, Kelly, Altermann, & Leahy, 2008).

The thesis consists of a further four chapters. The following chapter outlines the literature surrounding mitigation of methane and nitrous oxide emissions. This chapter focuses on the mitigation strategies that have been tested and proven. This is proceeded by a description of the methodology that is used within the research. Partial budgeting is the primary method to calculate physical and financial impacts of mitigation strategies. OVERSEER calculates the change in emissions from different scenarios. Main findings are then discussed in chapter 4, and the final chapter presents the study‟s summary and conclusions.

2 Literature Review

2.1 Mitigation of Methane Emissions from Ruminants

The New Zealand grazing animal is not subjected to the same conditions as many overseas farmed animals; it has fresh feed, it selects its feed, it is subject to peer pressure, and its behaviour is modified by the farmer‟s grazing management style. Fresh pasture metabolises differently from the same feed that has been dried (Ekern, Blaxter, & Sawers, 1965). In addition, animals housed indoors (as is the case in many overseas farm systems) rarely consume as much as animals grazing the same feed outdoors (Ulyatt, Thomson, Beever, Evans, & Haines, 1988). So it is doubtful that data derived from dried feeds in a calorimeter would apply to grazing situations. The creation of the sulphur hexafluoride tracer technique by Johnson et al. (1994) meant that it is now possible to take methane measurements from grazing animals.

There have been numerous suggestions to reduce methane emissions from grazing livestock. The specific measures fall into the following general categories: farm management to directly reduce emissions, farm management to increase output, manipulation of the ruminal microbial ecosystem, anti-methanogenic feed additives, and genomics. These sections will be broken down further into more specific strategies below.

2.1.1 Farm Management to Directly Reduce Emissions

Farmers are faced daily with a range of farm management choices to maximise both animal welfare and financial profit. Implementing a policy that charges farmers for emissions, such as the Emissions Trading Scheme (ETS), will impose an additional factor for farmers to consider. Therefore, farmers can change current management practices to reduce emissions once a cost for emissions has been imposed. Altering the animal‟s diet composition and reducing animal numbers are two ways to directly reduce ruminant emissions. These are discussed in turn below.

There are naturally occurring plant compounds that appear to have antimethanogenic properties. Johnson and Johnson (2002, as cited by O'Hara, et al., 2003) expose a number of plant compounds that seemingly have such an effect. Woodward, Waghorn, Ulyatt, & Lassey (2001) found a depression of methane emission when feeding dairy cows and sheep a condensed tannin, as did Waghorn, Tavendale, & Woodfield (2002) when sheep were fed *L pedunculatus*. Ulyatt, Lassey, Shelton, & Walker (2002) found that under some conditions methane emissions were severely reduced in both sheep and dairy cows when grazed on kikuyu grass, suggesting the presence of unidentified suppressing compounds. Such observations indicate that there are compounds to be found in pasture plants that offer the prospect of methane reduction in the environment if they can be bred into competitive pasture plants. The time required to breed and distribute the plant throughout the country should not be underestimated (O'Hara, et al., 2003). Forage legumes are another way that farmers can mitigate methane emissions.

When ruminant animals are fed forage legumes, it is possible that emissions are lower than when fed predominantly grasses (McCaughey, Wittenberg, & Corrigan, 1999; Waghorn, et al., 2002). However, the reduction does not happen in all cases (van Dorland, Wettstein, Leuenberger, & Kreuzer, 2007). The explanations for the possible reduction in emissions are the presence of condensed tannins (CT), lower fibre content, and higher DMI, combined with a faster passage to the rumen. Although there are compositional differences between grasses and forage legumes, deviations in methane (CH_4) emissions may be as a result of maturity at the time of harvest. For example, Chaves et al. (2006) found that CH_4 production was higher in animals that were fed alfalfa compared to grass pasture, as alfalfa is of higher maturity than grass. Accordingly, methane emissions can occasionally be higher due to longer fermentation of feed in the rumen, which invariably leads to greater forage intake and improved animal productivity (Beauchemin, Kreuzer, O'Mara, & McAllister, 2008). Reducing animal numbers is another method for farmers to mitigate methane emissions.

As enteric methane emissions from livestock are the predominant source of methane, reducing livestock numbers would aid in meeting commitments as laid out by the

Kyoto protocol and ETS. The market place has influenced farming behaviour as stock numbers have fluctuated in response to farming profitability. For example, sheep numbers have declined in the past 20 years, as profitability has declined. This has led to land use changes from sheep farming towards dairying and forestry. Over the period 1990 to 2000 sheep numbers reduced by 12.8 million to 45.1 million total units (Clark & Ulyatt, 2002). The net outcome is methane emissions have increased slightly from 1098 to 1171 Gigagrams (Gg)/year. Sheep numbers as of June 2007 were 38.5 million (Statistics New Zealand, 2007). Over 1990 to 2000 dairy numbers increased from 2.3 to 3.3 million animals (DairyNZ, 2008c). Over this time period emissions increased 49 percent (Clark & Ulyatt, 2002). As of 2008 there are 4.0 million dairy cows. Livestock numbers are the biggest influence on methane emissions from pastoral agriculture, and it is implicit that reducing numbers is the simplest way to reduce methane emissions (O'Hara, et al., 2003).

2.1.2 Farm Management to Increase Output

Livestock production is a very complicated subject. The grazing ruminant has emissions associated with two different states of production. The maintenance level of emissions for an animal is associated with a constant body weight and no production. Total emissions increase when the animal starts producing. O'Hara et al. (2003) uses the maintenance requirement emission factor of 26g/kg digestible dry matter intake (DDMI), derived from New Zealand work. At this rate maintenance methane emission would be 18 grams per day (g/d) for a 50kg ewe, 80 g/d for a 450 kg beef cow, and 105 g/d for a 450 kg dairy cow. Interestingly, the higher the feed intake above maintenance or the higher the level of production, the lower will be the methane emitted per unit of output. Hence from a production standpoint, the best strategy for a farmer faced with extra feed is to increase feed to existing animals rather than increase stocking rates. There are two important feed variables that the farmer can alter to reduce greenhouse gas emissions, the quantity and quality of feed. These are discussed below in turn.

Increasing feed intake decreases the methane emission per unit of feed intake, which can also be seen in terms of output through increases in milk production

(Kirchgessner, Windisch, & Muller, 1995) or live weight in beef cattle (McCrabb & Hunter, 1999). Table 2.1 (O'Hara, et al., 2003) displays the effects of increased feed intake on milk production and methane emitted per unit of milk. As intake increases the proportion of methane associated with maintenance decreases. Therefore, by feeding animals *ad libitum* it is possible to increase output and thereby reduce methane emission per unit of output.

Table 2.1: A calculation of the proportion of the methane emission attributable to maintenance or milk production in 450 kg grazing dairy cows

DDMI (kg/d)	Milk yield (kg/d)	CH_4 (g/d)[1]	% CH_4 associated with: Maintenance	Production	CH_4/milk (g/kg)
4	0	105	100	0	
7.9	12	206	51	49	17.2
10.5	20	272	39	61	13.6
11.7	24	305	34	66	12.7

(Source: O'Hara, et al., 2003)

The type of diet fed to a ruminant can have a major effect on the production of methane. Given the same milk production, cows that consume feed that has a higher digestibility produce a lower overall amount of methane. In addition, they consume less feed as dry matter (DM) digestibility increases. Therefore, by improving the nutritive value of the feed given to grazing animals, methane emissions should fall (O'Hara, et al., 2003). Improving pasture management can affect methane emissions through animal productivity improvement. This benefits farmers as less dietary energy is lost as CH_4 due to reduced fibre content of the sward when the quality of grazed pasture increases. This has been comprehensively demonstrated that improved pasture quality will reduce emissions on well managed intensive farming systems (Beauchemin, et al., 2008). Furthermore, it is expected that methane production will be lower with high concentrate feeds, compared to lower quality pasture based diets (Fahey & Berger, 1988).

The effect of increasing the level of concentrate in the diet has been well documented, concluding that such actions reduce enteric methane emissions. Increased roughage

[1] DDMI * 26

intake reduces the proportion of dietary energy converted to methane (Blaxter & Clapperton, 1965), mainly due to the associated change in fermented substrate from fibre to starch and the decline in ruminal pH. Also associated with the change in diet is increased animal production. Furthermore, milk quality is negatively affected once concentrates exceed approximately 50 percent of the diet. Alternatively, the change in diet may not necessarily reduce total national emissions, as more grain must be grown, processed and transported, creating additional emissions associated with growing grain crops (Beauchemin, et al., 2008).

Testing the potential emissions reductions, Lovett, Shalloo, Dillon, & O'Mara (2006) examined both on- and off- farm GHG emissions from production systems where concentrate feeding went from low to medium and then to high. Between the low and high scenarios, there were reductions in CH_4, N_20, and CO_2 of 9.5 percent, 16 percent, and 5 percent respectively. Similarly, Johnson, Phetteplace, & Seidl (2002) compared the whole farm GHG inventories, which include emissions associated with fertiliser synthesis, insecticide synthesis and application, transportation and processing. The authors found total farm GHG emissions increased as the proportion of forages in the diet increased, agreeing with the findings of Lovett et al. (2006). When more concentrates were added to the diet profitability rose as emissions decreased, encouraging farmers to implement this strategy. Alternative crops can be used in place of grass silage to reduce methane emissions.

Alternative crops such as maize and whole crop small grain silages typically yield comparable dry matter to grass and grass silage, but can increase animal production. There are three different ways alternative crops affect enteric methane emissions. Firstly, the starch within grain silages promotes the production of propionate as opposed to acetate in the rumen. Secondly, by increasing the amount of voluntary intake these crops promote post-ruminal digestion. Thirdly, the combination of increased voluntary intake and post ruminal digestion improves animal performance, thereby reducing emissions of CH_4 per head of animal product (O'Mara, Fitzgerald, Murphy, & Rath, 1998). The whole farm systems need to be examined when production changes from grass silage to crops, as these effects are unclear (Beauchemin, et al., 2008).

Other alternative food sources farmers can feed animals to reduce CH_4 emissions are lipids, such as whole cottonseed, coconut oil, and palm kernel oil, that are not affected by ruminal digestion in the diet. It has been discovered that high levels of lipids can reduce methane emissions up to 40 percent (Jordan, Lovett, Hawkins, Callan, & O'Mara, 2006; Machmuller & Kreuzer, 1999), although reductions of around 10-25 percent are more likely on a commercial scale. There are many factors which affect the usefulness of lipids to reduce methane, including; level of supplementation, fat source, fatty acid profile, form of administration, and the type of diet. Generally, it is recommended that fat in the diet does not exceed 6-7 percent of dry matter otherwise a depression of dry matter intake may occur, negating the advantages of increased energy density of the diet. The addition of lipids affects CH_4 production through the reduction of ruminal organic matter fermentation, the activity of methanogens and protozoal numbers, and for lipids which are high rich in unsaturated fatty acids through hydrogenation of fatty acids (Johnson & Johnson, 1995).

2.1.3 Manipulation of the Ruminal Microbial Ecosystem

Normal functioning of the rumen produces methane emissions, as metabolic hydrogen is removed during microbial metabolism. Anaerobic conditions within the rumen alter the mix of emissions towards methane. Methanogens using hydrogen within the rumen prevent hydrogen build-up, which direct the mitigation strategies towards redirecting and decreasing hydrogen within the rumen. Three factors that alter the functioning of the ruminal microbial ecosystem include protozoa, defaunating agents, and ionophores.

Protozoa play an active role in the fermentation of animal sugar and fibre. Methanogenic bacteria have been observed on the exterior surface of ciliate protozoa in the rumen (Finlay, et al., 1994), and it has been reported that the removal of protozoa from the rumen (defaunation) is associated with a decrease in the production of methane (Ushida, Tokura, Takenaka, & Itabashi, 1997). However it remains unclear as to the effectiveness defaunation has in reducing emissions due to inconsistencies between in vitro and in vivo data, in both the short- and long- term (Ranilla, Morgavi, & Jouany, 2004). Therefore, McAllister and Newbold (2008) reexamine the effect of protozoa and found that the lambs had methane emissions 26 percent less compared to the control group, per kg DM intake. In addition, the proportions of methanogens in total bacteria population were smaller in protozoa-free lambs.

Methanogens living in a symbiotic relationship with protozoa can account for about 40 percent of rumen methane emissions (Hegarty, 1999) and defaunation results in reductions in emission of about 20-50 percent (Kreuzer & Kirchgessner, 1986). Defaunating agents appear to disrupt the close symbiotic relationship between methanogenic bacteria and protozoa. There is a fine line between killing the protozoa and the animal; therefore toxicity may restrict an agent‟s routine use on animals.

"Ionophores such as monensin are antimicrobials that are typically used in beef and dairy commercial production to modulate intake, control bloat, and improve efficiency of meat and milk production" (McGuffey, Richardson, & Wilkinson, 2001, p.23). Monensin impacts the rumen by increasing the acetate-to-propionate ratio of the volatile fatty acids in rumen fluids. Protozoal numbers may also be reduced by monensin.

Monensin is administered either as a diet premix, or provided through a slow release capsule that is inserted into the rumen. The literature to date has suggested that lowering CH_4 with monensin is dose dependant. Little or no effect was found for doses <20 ppm (Waghorn, Clark, Taufa, & Cavanagh, 2007; Vugt, Waghorn, Clark, & Woodward, 2005), whereas higher doses (24-35 ppm) reduced CH_4 production (g/day by 4-10 percent and g/kg DMI by 3-8 percent) in beef cattle and dairy cows (McGinn, Beauchemin, Coates, & Colombatto, 2004; Odongo, et al., 2007; Sauer, et al., 1998; Vugt, et al., 2005). Guan, Wittenberg, Ominski, & Krause (2006) reported a 30 percent short term reduction in high or low forage diets when administered monensin. The relatively high dose rates needed to reduce CH_4 corresponds to the levels which are typically fed to improve feed efficiency in beef and dairy cattle. Unfortunately the mitigation properties of ionophores do not persist over time (Johnson & Johnson, 1995). Conflicting this proposition, Odongo, et al. (2007) discovered that the adaption to ionophores does not always occur as their study did not see any return to original levels over a 6-month period. The ability to use monensin for methane mitigation over the long term appears to be unviable, due to the growing consumer pressure to reduce the use of antimicrobials in animal agriculture. In addition, European regulations prevent its use within member countries (Beauchemin, et al., 2008).

2.1.4 Anti-Methanogenic Feed Additives

Additives with anti-methanogenic properties can be supplemented to current purchased feed to reduce methane emissions in the rumen. They can either directly reduce the supply of hydrogen (halogenated analogues, bacteriophages and bacteriocins), or provide alternative hydrogen sinks to reduce methane emissions (alternative hydrogen acceptors and organic acids). These mitigation strategies are described below.

Halogenated analogues are potent inhibitors of methane formation in the rumen, although the methanogen species differ in their sensitivity of these analogues (Ungerfeld, Rust, Boone, & Liu, 2004). Tests have shown that Bromoethanesulfonic (BES) is particularly effective at inhibiting methane emissions (Dong, Bae, McAllister, Mathison, & Cheng, 1999), and can reduce methane emissions from 3.9-0.6 percent of gross energy intake of feedlot steers (Tomkins & Hunter, 2003). Also, administration of more simple halogens such as chloroforms can cause significant reductions in the level of methane emissions. Reductions due to halogenated analogues are often transitory with emissions returning to original levels within a couple of days after application, which may reflect a compositional change in the population of methanogens from analogue-sensitive to analogue-insensitive species. Currently it appears that the use of halogenated analogues will not gain widespread acceptance as a mitigation strategy due to the increase in regulatory restriction and movement away from chemically synthesised feed additives in livestock diets (McAllister & Newbold, 2008).

Bacteriophages and Bacteriocins are biological control strategies that could prove effective to directly inhibit methane production. These obligate microbial viruses work by affecting “both bacteria and archea, and lyse their hosts during the lyctic phase of their development" (McAllister & Newbold, 2008, p.8). To date no phages specific to rumen methanogens have been reported. This technique has been primarily developed for lowering the prevalence of the human pathogen E. Coli.

Addition of unsaturated fatty acids to the rumen will decrease methane emission, where their effect is through two distinct channels. The first is that unsaturated fatty acids act as a potential alternative sink for hydrogen, and secondly, large doses are toxic to rumen microorganisms and depress digestion. Johnson and Johnson (2002) cite additional evidence that medium chain fatty acids may suppress methane more than long chain fatty acids. Organic acids also act as an alternative hydrogen sink for methane emissions.

Dicarboxylic acids are precursors to propionate production in the rumen, hence, have the ability to act as an alternative hydrogen sink in the formation of methane. Newbold et al. (2005) completed an extensive study on the potential of propionate precursors, and found that fumarate and acrylate produced the most consistent reductions in methane formation in the batch culture. Fumarate has been shown to reduce methane output by 38 percent in continuous fermenters with forage substrate (Kolver, Aspin, Jarvis, Elborough, & Roche, 2004). Inclusion of multiple propionate precursors to the diet could yield effective inhibition strategies as the reductive pathways are different among organic acid sources.

There have been recent reports suggesting that supplementing the diet with fumaric acid (FA) can produce large reductions in methane emissions, but the results to date have been inconclusive. Organic acids such as fumarate and malate are key intermediates of the citric acid cycle and occur naturally in plants (ranging from 2 percent to 8 percent of dry matter) (Jones & Barnes, 1967). As hydrogen (H_2) is used to reduce fumarate, there is a decline in H_2 available for methanogenesis in the rumen. The empirical evidence to support this hypothesis comes from the work of Asanuma et al. (1999), Lopez et al. (1999), and Kolver et al. (2004).

2.1.5 Genomics

Currently, there is a wide variety of natural habitats being genome-sequenced with the aim of gaining a better understanding of ruminant biology. Greater in-depth understanding of ruminant biology can lead to the identification of targets for gut-associated methanogens. Genome comparisons are identifying common genes that define a methanogen, whilst differences provide an insight into adaptations that allow methane survival and persistence under a variety of environmental conditions. Rumen methane mitigation strategies in the long run need to consider alternative hydrogen routes in the absence (or decreased levels of) methanogenesis to maintain rumen function. The two main possibilities are enhancing rumen microorganisms that carry out reductive acetogenesis, and promotion of organisms that consume reducing equivalents during the conversion of metabolic intermediates into propionate and butyrate. Greater understanding of methane oxidisation in the rumen may also lead to future options for methane mitigation (Attwood & McSweeney, 2008).

However, when choosing high and low methane emitters, researchers have encountered a variety of problems, such as the ability to replicate the study and find similar rankings within a group (Goopy & Hegarty, 2004; Pinares-Patino, Ulyatt, Lassey, Barry, & Holmes, 2003). Vlaming, Lopez-Villalobos, Brookes, Hoskin, & Clark (2008) identify that there is significant variation between animals and also within animals themselves, pointing to a variety of different hypotheses as to why this occurs. One possible explanation for the lack of repeatability is that animals can change ranks with respect to time.

One future mitigation strategy suggests that vaccination against methanogens may be effective to reduce methane emissions. Wright et al. (2004) immunised sheep with a mixed whole cell preparation from three different methanogens, having a favourable impact on the reduction of methane emissions (per kg DM intake) by 7.7 percent. The diversity of the methanogens in the rumen may possibly be influenced by geographic location and diet, making it difficult to find a broad-spectrum methanogen vaccine that is effective across a wide variety of geographic and production systems (Wright, Toovey, & Pimm, 2006).

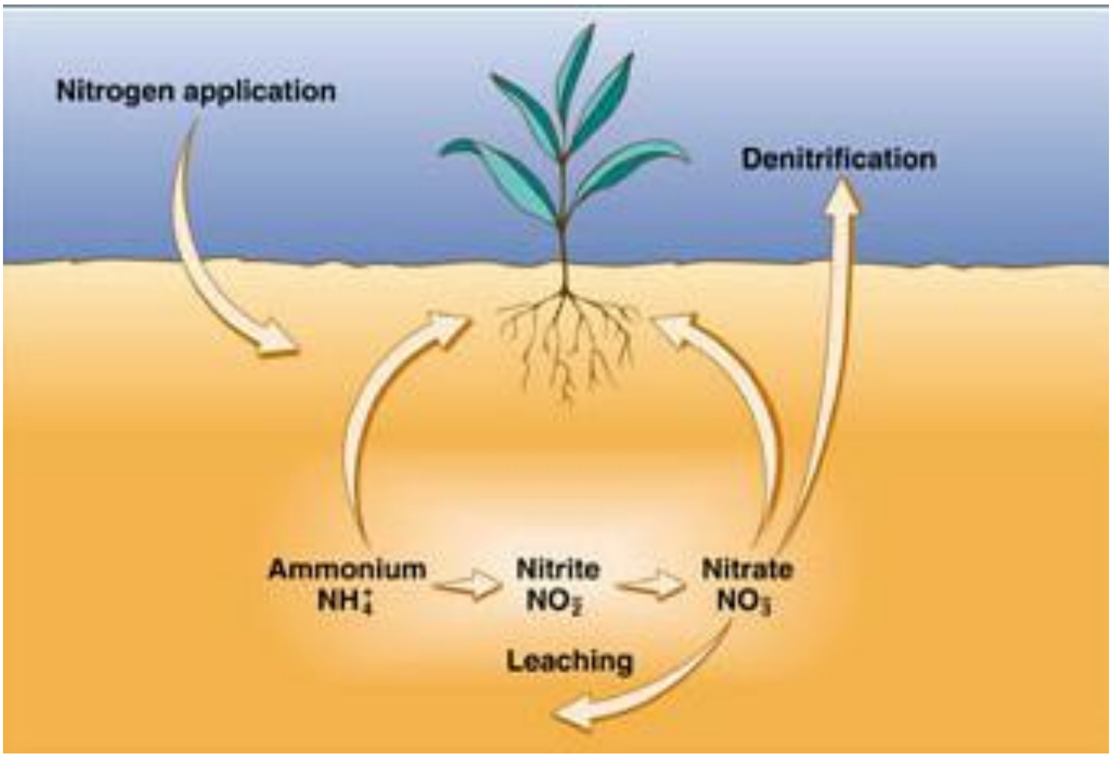
2.2 Mitigation of Nitrous Oxide Emissions from Ruminants

Nitrous oxide directly comes from two soil microbial processes: nitrification and denitrification. The former is an aerobic process that oxidises ammonium (NH_4^+) to nitrate (NO_3^-) with nitrous oxide as a by-product (N_2O), whilst the latter is an anaerobic process that reduces nitrate (NO_3^-) into nitrogen (N_2), with nitrous oxide (N_2O) an intermediate. Indirectly N_2O can form when: nitrogen emitted as ammonia and nitric oxides is deposited on land; nitrate is lost by leaching or run-off to waterways, and; nitrogen in foodstuffs is converted to sewage. Although nitrous oxide can come from a variety of environmental pathways (Oenema, et al., 2005), field measurements of N_2O generally indicate soil conditions that are consistent with denitrification. However, this is often an essential part of intensive farming for denitrification to convert nitrogen inputs from urine, urea and ammonium based fertilisers, into NO_3^-.

Nitrification is an aerobic process, requiring oxygen, whereas denitrification is an anaerobic process that does not require oxygen. The most important factor controlling nitrification is the level of ammonium in the soil, where this availability is controlled by fertilisation, animal wastes, mineralisation and immobilisation rates, plant uptake, ammonia volatilisation, cation exchange and diffusion. Water is required for the growth of the organisms, but the content also affects the rate of diffusion of ammonium and oxygen (Schmidt, 1982).

General conditions required for biological denitrification include: microorganisms with the capacity to denitrify; nitrate and other available organic matter; restricted oxygen supply; and a favourable pH and temperature environment (Firestone, 1982). Usually, excessive water causes a restricted oxygen supply, where denitrification usually occurs when soil water contents >60 percent of water filled pore space (Linn & Doran, 1984). In aerobic soils denitrification can occur in anaerobic micro sites in soil aggregates (Parkin, 1987), or in areas of high carbon content where active microbial activity rapidly consumes all of the available oxygen (Firestone, 1982). Other factors can influence denitrification by interacting with the control variables mentioned above; these include vegetation, crops, cropping pattern, soil type, soil texture and rainfall.

Figure 2.1: Process of nitrification and denitrification



(Source: University of Illinois, 2008)

Figure 2.1 displays two forms of nitrogen available for plant growth; ammonium and nitrate. Nitrate form of nitrogen is more vulnerable to groundwater leaching than ammonium, posing a greater risk to the environment and waterways. Nitrification is a microbial process where bacteria alter ammonium for direct use by plants. With denitrification, a bacterial process occurs whereby nitrates are unable to be used by plants.

There are many different soil and climatic factors that influence both nitrification and denitrification (Firestone, Firestone, & Tiedje, 1980). However, with respect to agriculture the most prevalent influence is the coincidence of high soil NO_3^- levels and low soil aeration (Eckard, Chen, White, & Chapman, 2003). Therefore, abatement strategies for agriculture that will be most effective if they reduce the availability of soil nitrate or improve soil aeration.

For New Zealand, the major form of land use (13 x 10^6 ha) involves dairy cattle, sheep, beef cattle, deer and goats grazing on pasture that is covered with grass and legume (O'Hara, et al., 2003). These animals modify the characteristics of pasture nitrogen uptake and soil physiology, through treading and depositing excreta directly onto the pasture (Jarvis, Scholefield, & Pain, 1995). As shown by table 2.2, animals utilise very little of the nitrogen they ingest, therefore the excess nitrogen ingested is excreted in dung and urine (van der Hoek, 1998).

Table 2.2: Global animal production in 1994, in terms of nitrogen (measured in Tg)

Animal	Intake	Total Products	N-Efficiency
Cattle	64.417	4.959	7.7%
Buffaloes	7.102	0.37	5.2%
Sheep	11.617	0.719	6.2%
Goats	5.726	0.207	3.6%
Pigs	12.23	2.513	20.5%
Chickens	9.495	3.211	33.8%
World total (for all categories)	**114.355**	**12.004**	**10.5%**

(Source: van der Hoek, 1998)

The largest source of nitrous oxide is from the animal, where the nitrogen contained within the soil-plant-animal system is returned through excretion (Clark, Pinares-Patiño, & Klein, 2005). Plants require larger amounts of nitrogen than animals for optimal growth rates. Hence, between 75 and 90 percent of ingested nitrogen by ruminants is excreted back onto pasture (Whitehead, 1995).

There have been numerous studies which propose how to reduce the amount of nitrous oxide as a result of grazing animals on pastures (Clark, de Klein, & Newton, 2001; Clemens & Ahlgrimm, 2001; Kammann, Grunhage, Muller, Jacobi, & Jager, 1998; Kroeze, 1998; Misselbrook, Chadwick, Pain, & Headon, 1998; Oenema, Velthof, Yamulki, & Jarvis, 1997; Stevens & Laughlin, 1998; Velthof & Oenema, 1997). Generally these techniques can be broken down into three distinct groups, animal interventions, fertiliser or soil management, and livestock production management (Velthof, van Beusichem, & Oenema, 1998).

2.2.3 Animal Interventions

Animal interventions deal directly with altering animal handling/management practices and technologies that directly mitigate greenhouse gas emissions. Identification, transfer of knowledge, and delivery mechanisms for these strategies are the major barriers to implementation at the farm level. The animal interventions that are discussed below include the animal delivery of a nitrification inhibitor, animal breeding, reducing soil compaction, and livestock management.

Within the literature there is significant evidence that nitrification inhibitors reduce N_2O emissions from urine patches (Di & Cameron, 2002, 2003, 2006). In an alternative approach, Ledgard et al. (2008) showed that animals can be supplemented with an inhibitor with the intention of the inhibitor being excreted with urine in an unaltered form. This will directly apply the nitrification inhibitor to the urine patch, where the concentration of nitrogen is at its highest. Such an approach is likely to maximise the reduction potential of the inhibitor and minimise quantity required for application. Further research is needed to quantify the potential abatement and production effects of this DCD delivery mechanism.

Growing or lactating cows are more efficient at using nitrogen than animals at maintenance. Increasing milk production will partition more nitrogen to milk formation rather than being excreted in urine (Satter, Klopfenstein, & Erickson, 2002). Recently it has been discovered that there is a genetic link between milk yield and efficiency of feed conversion, indicating that it is worthwhile to breed for selection (Simm, 1998). Hence breeding for feed conversion efficiency should result in more animals that partition nitrogen for milk production rather than losing it through excretion. Similarly there is the possibility that methane production per animal and per unit of production could be reduced.

The effects of soil compaction on nitrous oxide emissions have been studied by a number of different scientists in different situations (Abbasi & Adams, 1999; Ball & Ritchie, 1999; Ball, Scott, & Parker, 1999; Situla, Hansen, Situla, & Bakken, 1997). McTaggart, Douglas, Clayton, & Smith (1997) found that nitrous oxide emissions of compacted soils were twice that of unaffected soils. Hansen, Maehlum, & Bakken et al. (1993) observed that concentrations of nitrous oxide in compacted soil were seven times greater than un-compacted soil, but emissions were only 1.5 times greater. In addition treading by cattle could increase soil compaction and emissions of nitrous oxide by a factor of two (Oenema, et al., 1997). It is apparent from these findings (and others) that tillage and traffic should be reduced to minimise soil compaction or the creation of plough pans, which result in increased denitrification and nitrous oxide emissions.

Nitrous oxide emissions from animal excreta are likely to be highest during the wet winter and autumn period (de Klein, Sherlock, Cameron, & van der Weerden, 2001). Therefore, keeping dairy cattle on wintering-pads during these wetter months, and collecting the excreta then re-utilising it as effluent can reduce nitrous oxide emissions. Emissions from effluent are smaller than those of excreta if applied in the correct manner (Oenema, et al., 1997). In addition, nitrate leaching losses would be reduced by this measure to the extent of 45-55 percent (de Klein & Ledgard, 2001).

2.2.4 Feed Based Interventions

Methods proposed for manipulating the diet of animals to improve the uptake of nitrogen, and reduce the amount of nitrogen excreted, include; lowering protein content of the diet (Misselbrook, et al., 1998); increasing the carbohydrate content of the diet so that more microbial protein is synthesised and less ammonia is lost from the rumen (Dove & Robards, 1974; Kebreab, France, Beever, & Castillo, 2001); and increasing the amount of condensed tannins in the diet (Min, Fernandez, Barry, McNabb, & Kemp, 2001).

The proportion of protein ingested affects excretion and nitrogen efficiency. Animals on a maintenance-only diet require approximately 7 percent of their dry matter intake to consist of crude protein; pregnant animals require 10-12 percent, while lactating animals require 15-20 percent. Ruminants on grasses that are high in protein tend to ingest more than is required, resulting in additional excretion (Whitehead, 1995). Therefore, it is imperative to balance the protein-to-energy requirements of the animal to minimise the N_2O emissions resulting from excess urinary nitrogen excretion.

Misselbrook, Powell, Broderick, & Grabber (2005) showed that dairy cows fed 14 percent crude protein as part of their diet excreted 29 percent less nitrogen compared to dairy cows fed 19 percent crude protein.

Carbohydrates are an important factor in nitrous oxide emissions. When offered a choice between „high" and „low" water soluble carbohydrate concentrations, it has been proven that ruminants prefer „high" water soluble carbohydrate concentrations. Ciavarella, Dove, Leury, & Simpson (2000), found that merinos selected 2.6 times more of the „high" quality feed compared to the „low" quality pasture. This result, coupled with previous work in the area (e.g. Dove & Milne, 1994; Leury, Siever-Kelly, Gatford, Simpson, & Dove, 1999), suggest that pastures with higher water soluble carbohydrate would result in higher dry matter intake, improved efficiency of microbial protein synthesis (Dove & Milne, 1994) and better animal performance (Ciavarella, et al., 2000). Breeding "high sugar" ryegrass cultivators to improve nitrogen efficiency in dairy cattle has also proved effective (Clark, et al., 2001).

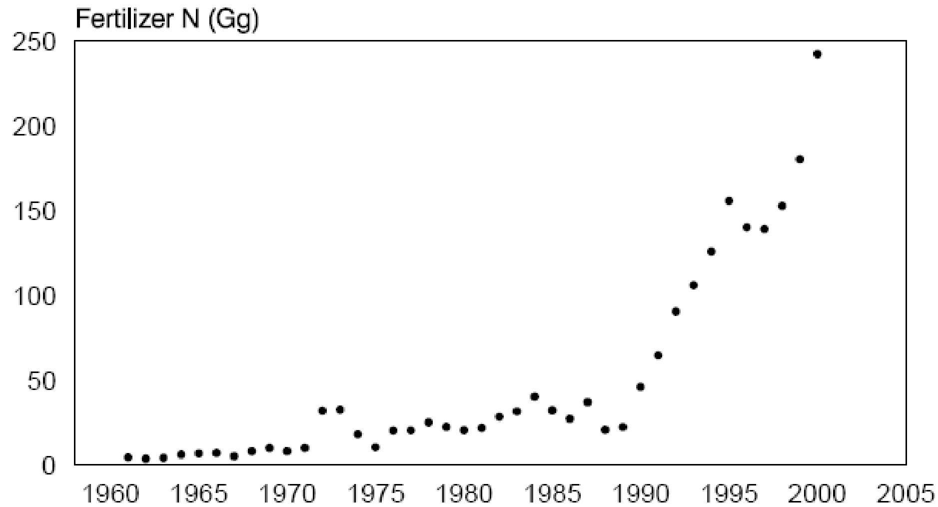
"Condensed tannins (CT) complex with protein in the rumen and protect them from microbial digestion, resulting in either more efficient digestion or the tannin protein complex being excreted in the dung" (de Klein & Eckard, 2008, p.16). Carulla, Kreuzer, Machmuller, & Hess (2005) showed that sheep fed a CT extract had an increased partitioning of nitrogen from urine to dung, where urine nitrogen decreased by 9.3 percent as a proportion of total nitrogen excreted. Similarly, Misselbrook et al. (2005) found that dairy cows on a 3.5 percent CT diet excreted 25 percent less urine, 60 percent more dung, and 8 percent more nitrogen overall compared to cows on a 1 percent CT diet. The inclusion of CT appears to reduce nitrogen excretion in urine, increase nitrogen excretion in faeces and improve the nitrogen retention in the animal. This approach reduces the concentration of nitrogen in urine leading to a reduction in emissions.

2.2.5 Soil or Management Interventions

Of the factors that affect nitrous oxide emissions some are out of the control of farmers, such as soil type, rainfall, season, and temperature. However, there are factors which farmers can control. These include; soil aeration (affected by tillage methods), water status (controlled by irrigation and drainage), fertiliser type, amount, method and time of application, soil pH adjusted by application of lime (Stevens & Laughlin, 1998), supply of organic matter (Granli & Bockman, 1994) and compaction of soil by animals and farm machinery (Abbasi & Adams, 1999).

Most of the international research on nitrous oxide emissions world-wide has focussed towards reducing emissions from cropped soils (Cole, et al., 1997; Granli & Bockman, 1994; McTaggart, Clayton, & Smith, 1994; Mosier, Duxbury, Freney, Heinemeyer, & Minami, 1998; Smith, McTaggart, & Tsuruta, 1997). However, many of the techniques are considered to be not applicable to New Zealand pastoral systems as relatively little synthetic nitrogen fertiliser is used (Clark, et al., 2001). In contrast with the comparatively lower overall level of synthetic nitrogen use, the rate at which New Zealand has used fertiliser has increased substantially over the past 10 years. Therefore, mitigation options for synthetic fertilisers need to be considered as it is likely to play an increasing role in the future.

Figure 2.2: Nitrogen fertiliser use in New Zealand since 1960 (units in Gigagrams)



(Source; O'Hara, et al., 2003)

The amount of nitrogen contained in urine (equivalent to 500 kg N ha^{-1} for sheep, and twice that for cattle) is much greater capacity that plants can assimilate it (Cameron, Di, & Condron, 2002; Jarvis, et al., 1995; Silva, Cameron, Di, & Hendry, 1999). It is generally accepted that an increase in the amount of nitrogen applied will result in an increase in the emission of nitrous oxide (O'Hara, et al., 2003). Therefore, the excess nitrogen can be lost to a variety of competing systems, such as ammonia volatilisation, nitrification-denitrification, or leaching with indirect effects on nitrous oxide.

The rate, timing and source of nitrogen fertiliser are important management factors that affect the growth of pasture, and the magnitude of lost nitrogen. In conditions that promote denitrification, nitrous oxide emissions increase exponentially with the rate of nitrogen applied in any application (Eckard, Johnson, & Chapman, 2006; Mosier, Parton, & Hutchinson, 1983; Whitehead, 1995). It is now common practice for farmers to restrict fertiliser application, in New Zealand and Australia, to 50-60 kg nitrogen fertiliser per hectare in any single grazing rotation with urea as the main source. This application rate should be lower for shorter grazing or lower expected growth rates (Eckard, et al., 2006; Ledgard, 1986). Emission reductions primarily occur through the reduction of total amount of nitrogen applied and the timing of application in relation to soil moisture levels.

There is a trade-off as to the frequency and quantity of nitrogen application. Ortiz-Monasterio, Matson, Panek, & Naylor (1996) found that several smaller fertiliser applications during the growing season is more effective at delivering nitrogen to the plant as opposed to one large dose at the beginning of the season. Where there is a chance for the fertiliser to be applied through irrigation it should be utilised (Ortiz-Monasterio, et al., 1996). This mitigates some of the costs associated with multiple applications to conventional crops, whilst fine-tuning the growing requirements of the plants. The method has the advantage of low cost, intertwined with simplicity and convenience (Muirhead, Melhuish, & White, 1985).

Applied nitrogen fertiliser has a very low efficiency of use in agriculture, caused foremost by large losses of nitrogen in gaseous form (Peoples, Freney, & Mosier, 1995). It has been demonstrated that any strategy which increases the efficiency of applied nitrogen use will reduce emissions of nitrous oxide (Bronson, Mosier, & Bishnoi, 1992; Minami, 1997). In general N_2O can be reduced by management practices which optimise the crop‟s natural ability to compete with processes whereby plant available nitrogen is lost from the system, i.e. ammonia volatilisation, nitrification-denitrification, leaching, and run-off. If the plant can utilise nitrogen more efficiently, then less nitrogen will be required to meet the demand for food, leading to a reduction in nitrous oxide emitted into the atmosphere.

Over the last three decades, food production systems have changed along with animal production and meat consumption, which has been increasing much more rapidly than crop production. The imbalance has resulted in an increase in the amount of nitrogen excreted by livestock, with not all of the nitrogen being returned back to the field, as animal production is not necessarily conducted in the same geographical area as crop production. Returning to a more traditional form of crop and animal production systems where animal wastes are returned to the field, would keep the nitrogen cycle held tightly with the food production system, keeping soils more fertile and minimising nitrogen losses (Mosier, et al., 2002).

By using specific slow release fertiliser formations to release nitrogen as the plants require nitrogen, this should be able to provide sufficient nitrogen in a single application to satisfy plant requirements, whilst simultaneously providing low concentrations of mineral nitrogen in the soil throughout the growing season. In this case, any gases that would be lost from the soils would be minimal due to the limited substrate. Many different slow release methods have been suggested (Shaviv & Mikkelsen, 1993; Shoji & Kanno, 1994; Vallejo, Diez, Lopez-Valdivia, Gasco, & Jimenez, 2001) with significant advances in the formulation of these materials (Smith, et al., 1997). Large reduction in the emissions of nitrous oxide have been achieved using polyolefin-coated ammonium nitrate (trade name "Long") instead on uncoated fertiliser nitrogen (Smith, et al., 1997).

It has been shown that plant uptake of nitrogen fertiliser can be improved and total losses reduced from the levels achieved with surface broadcasting by incorporation or deep placement of the nitrogen fertiliser (Rees, et al., 1997). Placement of the nitrogen deep in the soil in an anaerobic zone will lower the N_2O/N_2 ratio when denitrification occurs. Through placement below the soil ammonia volatilisation also decreases by providing a better physical barrier in the form of soil to trap any ammonia liberated. Rees et al. (1997) found that improved fertiliser placement could increase the recovery of fertiliser nitrogen by 20-30 percent. Relative recoveries and level of nitrogen loss can also be influenced by fertiliser composition, along with the rate and timing of the application (McTaggart et al., 1994; Smith, et al., 1997; Strong, Saffigna, Cooper, & Cogle, 1992).

Reduced or no till farming systems, in which plant residues are retained and soil disturbance minimised, encourages reduced nitrogen mineralisation. However there is evidence which indicates that no-till systems suffer greater losses through denitrification than those under conventional cultivation (Ball, et al., 1999; Smith, et al., 2000). This may be because in no-till soils there is a greater pool of substrate nitrogen in the surface layers (MacKenzie, Fan, & Cadrin, 1998), greater bulk density resulting in reduced diffusion of air in the surface layers, larger and more anaerobic aggregates, increased water content due to greater water conservation, and greater concentrations of organic matter near the surface to increase carbon availability. These factors make it more favourable environment for denitrifying microorganisms and greater losses of nitrous oxide (Aulakh, Rennie, & Paul, 1984; Ball, et al., 1999; Smith, et al., 2001; 2000).

Nitrification inhibitors are chemical compounds that slow the formation of nitrate (NO_3^-) from ammonium (NH_4^+) based fertilisers in soils, or from urine, thereby reducing the amount of nitrous oxide emissions (Di & Cameron, 2002). There are two main commercially available nitrification inhibitors for use at the farm level, nitrapyrin and dicyandiamide (DCD). These coatings have been shown to be effective in reducing N_2O emissions by approximately 80 percent (reviewed in de Klein, et al., 2001). Both are effective in reducing emissions from animal urine, as research in New Zealand and Australia have reported emission reductions by 61-91 percent and pasture yield increases of 0-36 percent (Di & Cameron, 2002, 2003, 2006; Di, Cameron, & Sherlock, 2007). However, many of these studies have been conducted under conditions that promote N_2O emissions, and the possible reductions tend to be at their maximum. Caution should be taken when extrapolating emissions potential when there are less favourable conditions for reducing N_2O.

Reports in New Zealand have shown that the use of DCD application to urine patches has reduced N_2O emissions by up to 78 percent (Di & Cameron, 2003), and reduced nitrate leaching by up to 45 percent (Di & Cameron, 2002). Therefore, the use of DCD on grazed pasture offers potential to reduce emissions resulting directly from animal production. Kelly, Phillips, & Baigent (2008) found effectiveness of DCD was lower in Victoria compared to results presented in New Zealand, likely to be as a result of soil conditions, and in particular temperature. As the capacity of DCD depends on several factors, including temperature, soil humidity and treatment doses (Di & Cameron, 2004), it is imperative to test DCD under local conditions to find its effectiveness. Currently New Zealand is considering accounting for inhibitors in the national inventory calculations, which will give farmers an incentive to adopt the technology at the farm level.

Recent research has shown that restrictive grazing practices can reduce direct and indirect emissions of N_2O by up to 10 percent (de Klein, Smith, & Monaghan, 2006; Luo, Ledgard, & Lindsey, 2008; Schils, Verhagen, Aarts, Kuikman, & Sebek, 2006). In the referenced studies, animals were allowed to graze for 3-15 h per day, and were kept off pasture either indoors or on a feed pad for the remainder of the day. Schils et al. (2006) reported that a combination of the reduced grazing time and fertiliser use of Netherland study farms reduced emissions by around 50 percent when reported on a per unit of output scale, and around 10 percent on a whole farm basis. The improved nitrogen utilisation increased farm efficiency while reducing nitrogen losses, as production held constant. Luo et al. (2008) and de Klein et al. (2006) reported whole farm reductions in the level of emissions of 7-11 percent for restrictive grazing regimes, following subsequent land application of effluent collected when animals were kept on feed or stand-off pads, compared to conventional grazing.

2.2.6 Potential Future Interventions

The above techniques and technologies have been generally proven to reduce emissions and are at a stage that is at or close to implementation at the farm level. There are some technologies that are currently unproven, but hold promise for reducing nitrous oxide emissions in the future. Such technologies hold the key to further reducing emissions once all current technologies have been adopted. Genetic selection or engineering holds the greatest promise of the future mitigation strategies.

There is the potential for future genetic engineering or standard selection for the creation of forages that utilise more nitrogen, from a greater area of soil and grow in more difficult conditions. Such forages will leave fewer nitrates in the soil to be leached or denitrify. The current state of research points towards species with deeper or more adventitious root systems that could indeed improve nitrogen uptake by plants (Crush, Easton, Waller, Hume, & Faville, 2007). Also a possibility exists for engineering denitrifying bacteria to utilise alternative electron acceptors, other than nitrate or soil, thereby eliminating denitrification. However, the reality of genetic engineering is many years off as field trials and other tests are required first, along with consumer acceptance (de Klein & Eckard, 2008).

2.3 Agricultural Greenhouse gas Modelling

The economic and environmental impacts of global warming are largely uncertain, but can be estimated through the use of models. Estimates of regional greenhouse gas emissions from agricultural systems are needed to evaluate possible mitigation strategies with respect to environmental effectiveness and economic feasibility. There is a range of modelling methods used within the literature to quantify the economic impact, or impacts, of climate change policies. The focus of these models is primarily on either environmental or economic impacts of a particular region.

The NZIER (2008) produced a study that examines the impact of the New Zealand Emissions Trading Scheme (ETS) on the economy. They adapted a CGE model in concurrence with Monash University in Australia (the original model is called ORANI-G), to the New Zealand economic setting. The ORANI framework has been used and tested extensively on Australian policy analysis for nearly two decades, and has been similarly adapted for other nations (COPS, 2009). When calibrating the model for New Zealand, key assumptions have been checked with industry specialists, and therefore reflect best practice. The difference between this approach and other approaches is that it captures some of the adjustment costs in the economy, incorporates information on abatement costs specific to New Zealand, and quantifies the risk of producers shifting overseas and not reducing global emissions. The study evaluates the proposed ETS through two different modelling simulations. One simulating the impact of the proposed ETS as it stands, and the second quantifying the cost from the Government directly paying a tax for emissions. These two simulations are compared to forecast hypothetical future state of the economy without any attempts to meet Kyoto targets.

The results of the NZIER (2008) study conclude that the short-term cost of the ETS and Kyoto liability are; $900 million reduction in GDP (0.5 percent), $600 reduction in an average household‟s spending (0.8 percent), and reduction in employment equivalent to 22,000 jobs (1.0 percent). Also, the result of most of this cost comes from the setup of the ETS, rather than meeting the remainder of the Kyoto liability. In the longer-term, the ETS is four times more costly than the alternative of paying directly out of taxes. This incorporates the phase out of carbon credits, and covers the majority of all greenhouse gases. In 2025, the combined impact of an ETS and the cost of paying for an international emission reduction obligation (in today‟s prices), is; $5.9 billion reduction in GDP (-2.1 percent), $3,000 reduction in an average household‟s spending (-3.0 percent), and reduction in hourly wages equivalent to $2.30 per hour (-6.7 percent). It is noted that GDP per capita in 2025 will be higher than today, but will be lower than Australia‟s GDP per capita today. This impact will be largely incurred by the farming sector, as in 2025; dairy farming declines 12.9 percent, dairy land prices fall 40.6 percent, sheep and beef farming declines 6.6 percent, and the price of land used in sheep and beef farming falls 23.4 percent. Leakage is also a major concern for the agricultural sector, where emission reductions occur due to domestic production being shifted elsewhere in the world.

In another study, Hendy, Kerr, & Baisden (2006) use a model to simulate the effects of an agricultural land-use emissions charge and a reward for native forest and scrub regeneration. The model is a result of combined work between economists at Motu Economic and Public Policy Research, and scientists at institutes including Landcare Research, AgResearch, Scion/Ensis (Forest Research), and NIWA, and the model is known as LURNZ. This computer model simulates the effect of climate change related government policies on New Zealand rural land use. Importantly, LURNZ calculates the greenhouse gas implications of land-use change. The first version of the model splits land-use change into 25ha grid-cells, for four major rural land uses; dairy farming, sheep and beef farming, plantation forestry, and regenerating indigenous forest and scrub. LURNZ also splits the emissions associated with the land use into methane, nitrous oxide, and carbon dioxide emissions.

As a reference case, the study uses industry prices for key inputs to project land use and emission changes from 2003 – 2012. Based on this scenario, LURNZ projects that by 2012 dairy area will expand by 1.2 percent (18,000ha), sheep/beef area will contract by 2.8 percent (199,000ha), plantation forestry will expand by 17.4 percent (273,000ha), and regenerating forest and scrub will contract by 5.5 percent (92,000ha) compared to 2002 (Hendy, et al., 2006). When a carbon price is introduced, the study finds that dairy area contracts by 1 percent with the policy, whereas in the reference case it expanded by 1.2 percent. Sheep and beef area contracts by 0.3 percentage points more than in the reference case, plantation forestry stays similar, and regenerating forest and scrub contracts by 3.8 percentage points less than in the reference case. The land-use change caused by the policy reduces the annual growth rate in emissions during 2003 – 2012 from about 0.5 million tonnes of carbon dioxide equivalent per year in the reference case to about 0.4 million tonnes of carbon dioxide equivalent per year. The lower emissions rate from a charge based on land use equates to a 6 percent relative reduction in emissions over the first commitment period. This is a small reduction for a large emissions price. In addition, the study concludes that when rewards for regenerating scrub or forest, without a similar reward for plantation forestry, might negatively impact on plantation forestry, increasing emissions growth in the short-run. Results from this model are preliminary and therefore should be considered illustrative. A newer version of the model will be developed, which will be more robust.

Neufeldt et al. (2004) use the GIS-coupled economic-ecosystem model EFEM–DNDC to assess disaggregated regional greenhouse gas (GHG) emissions from typical livestock and crop production systems in the federal state of Baden-Wurttemberg, Southwest Germany. EFEM (Economic Farm Emission Model) is an economic farm production model based on linear programming of typical agricultural production that simulates crop and livestock production systems. In addition, it simulates all relevant farm management processes and greenhouse gas emissions. DNDC (DeNitrification DeComposition) is a process orientated ecosystem model that describes the complete biochemical process of carbon and nitrogen, including all trace gases. The model requires information on land use and management, plant phenology, soil characteristics, nitrogen deposition, and climate. These two models are then coupled together.

Analysis of the production systems showed that total GHG emissions from crop based production systems were considerably lower than from livestock based systems. Average production system GHG emissions for Baden-Wurttemberg were 4.5 Mg CO_2 eq ha^{-1}. Of the total 38 percent were derived from N_2O (direct and indirect soil emissions, and manure storage), 40 percent were from CH_4 (enteric fermentation and manure storage), and 22 percent were from CO_2 (mainly fertilizer production, gasoline, heating, and additional feed).

2.4 OVERSEER Nutrient Budgets Model

The OVERSEER nutrient budgets model (AgResearch, 2009) combines individual farm nutrient budgets along with indices derived from these nutrient budgets, enabling the end user to examine the impact of nutrient use and flows within a farm and possible environmental impacts. In addition, the model supports investigation of GHG mitigation options. Updated versions of the model are released as new research becomes available.

The goal of the model is for researchers and end users, such as farmers, farm consultants, and fertiliser representatives, to evaluate nutrient and management practices on farms. Researchers are able to assess the impact and sustainability of agricultural management using OVERSEER, whilst farmers are able to calculate when and where nutrients are required.

Best use of fertiliser (and nutrients) should consider agronomic, environmental, and economic factors, all of which are vital in sustainable agriculture. While maintaining productivity, nutrients are generally required to be added to the soil, while excessive use of nutrients may degrade the environment and are wasteful from an economic standpoint. Nutrient budgets are becoming more important when assessing the environmental impact and sustainability of agriculture and its management practices. The advantage of including nutrient budgets and greenhouse gas emissions into a single model is that it allows the user to assess some of the complex interactions that may occur between different components and loss pathways at a farm level.

2.4.1 Structure of the OVERSEER Model

There are three parts to the OVERSEER model; pastoral, greenhouse gas emission, and cropping and horticulture models[2]. The OVERSEER greenhouse gas emission inventory utilises algorithms and models which are implemented in New Zealand‟s greenhouse gas national inventory, but altered and improved as to include on-farm

[2] Only the greenhouse emission model will be described here. A brief outline for all the sub models is available at www.agresearch.co.nz/overseerweb.

management practices. Methane emissions are based on metabolic energy intake as described by Clark (2001). Nitrous oxide emissions are calculated based on the New Zealand IPCC inventory, which includes factors for direct loss from excreta, fertiliser and effluent, whilst also incorporating indirect losses from leached nitrogen and volatised ammonia. Since both methane and nitrous oxide have a higher global warming potential than carbon dioxide, they both need to be converted to CO_2 equivalents to compare aggregate gases. In addition to calculating methane and nitrous oxide emissions, carbon dioxide emissions are calculated from fuel, electricity, processing and other indirect farm activities. These factors are largely based on the data of Wells (2001). However, under the New Zealand ETS, agriculture will only need to account for nitrous oxide and methane with other major gases being captured at off-farm points of obligation.

The majority of this description on how OVERSEER operates with respect to methane and nitrous oxide, was taken from Wheeler, Ledgard, & de Klein (2008). Methane emissions in OVERSEER are calculated as per the national inventory method, outlined by Clark (2001). The national method "estimates monthly digestible dry matter intake (DDMI) for different animal types using a metabolic animal, metabolisable energy (ME) requirement model and typical pasture digestibilities, and multiplies DDMI by a CH_4 emission factor to get animal CH_4 emissions" (Wheeler, et al., 2008, p.99). The model requires user input of milk solids production, cow numbers, cow breed, and replacement policy (whether replacements are grazed on- or off- farm). Using information obtained from Livestock Improvement Corporation (2004), default values were obtained for each breed of dairy animal including weight, regional-based lactation length, milk ratio and fat ratio to estimate milk yield, and milk fat yield from milk solids production. The user can override these values if necessary.

With respect to sheep and beef, the model uses „stock units" to estimate annual metabolisable energy (ME) intake. This is a standard measure of animal intensity within New Zealand agriculture with one stock unit having an equivalent intake of 6,000 MJ ME/year (Woodford & Nicol, 2004). This is further distributed to a monthly ME intake using the distributions outlined by Clark (2001). An advanced option available is the stock unit calculator, which utilises animal weight, reproductive performance, the rate of change in weight of growing stock, and the time animals are on the farm. Also taken from Clark (2001) is the default monthly pasture quality, which represents digestibility and can also be overridden by the user. Regional pasture types and management differences are considered within the default values.

Different pasture types have discrete emission factors, and within OVERSEER five pasture types are recognised. Quality of pasture explains the variation of emission factors between grasses. Ryegrass/white clover (good quality pasture) has the lowest methane emission factor of 26.5g CH_4/kg DDMI (Clark & Ulyatt, 2002), and the highest emission factor is for Kikuyu or C_4-dominant pasture, with an emission factor of 34.5g CH_4/kg. The latter factor is also applied to brown top, unimproved pasture, and poor quality pasture. Finally, the methane emission factor for paspalum pasture was set midway between the two previous factors. The model then uses the lowest emission factor for all other food sources such as supplements and fodder crops, until better information is available on their emission factors. The model also includes alternate factors for sheep less than one year of age (Ministry for the Environment, 2006), and assumes a representative ratio of young stock in a breeding unit.

Dung emission factors are based on the work by Saggar et al. (2003), where the emission factors are 0.98, 0.69, and 0.98 g CH_4/kg dung dry matter (DM) for dairy, sheep, and beef respectively. Dung DM is estimated as: DM intake x (1 – digestibility) (Ministry for the Environment, 2006). Methane emissions from effluent ponds are included in the model but are not a significant source of methane emissions in New Zealand. Unfortunately the model does not include additional methane emissions from other effluent management systems such as spray application, holding ponds, and accumulated excreta from feed pads.

Nitrous oxide emissions are based on the IPCC inventory methodology (Ministry for the Environment, 2006), and estimated as the size of nitrogen inputs into the system multiplied by different emissions factors, depending on the source of the emissions (see table 2.3, taken from Wheeler et al. (2008) for the default emission factors). Direct estimates of nitrous oxide in the model include losses from fertiliser, excreta and effluent nitrogen inputs, and indirect losses from the same three processes, but associated with leaching and ammonia volatilisation (de Klein et al., 2004; 2001).

There are two modes available in the nitrous oxide model, where animal nitrogen intake is calculated by Wheeler et al. (2006), with animal ME estimated the same way as for methane, and excreta nitrogen estimated from animal intake less product removal in terms of nitrogen. Both the amount of fertiliser applied and the animal waste management system are farm specific. The first mode, which is the IPCC mode, uses the national distributional factors (FRAC values; table 2.3) to estimate urine and fertiliser volatilisation and leaching rates. Nitrous oxide emissions are then estimated by multiplying the quantity of nitrogen from a given source by the emission factor (shown in table 2.3). The calculations for nitrogen in effluent, solid waste and dry lot are discussed below.

In the second mode, the default or site specific mode, excreta nitrogen is calculated as per the first mode. The excreta nitrogen inputs are then partitioned into urine and dung (based on nitrogen concentration within the diet) and then distributed between paddocks, lanes, farm dairy or feed pads. Dairy or feed pads contribute to the effluent system. Nitrogen losses from leaching, volatilisation, and denitrification from each pool are estimated using the nutrient budget model. Factors that are accounted for when calculating each pool include; different sources of nitrogen, rainfall, and soil type (Wheeler, et al., 2006). The site specific emission factors are used within this mode.

Table 2.3: Default emission factors for estimating nitrous oxide emissions for a given source of nitrogen, and the distribution factors for estimated indirect nitrogen losses (FRAC) in the two different modes of the model

IPCC name	Source	Site-specific mode	IPCC mode
EF1	Direct emissions from fertiliser and effluent N input to soil and N deposited to lanes	0.01	0.01
$EF3_{PR\&P}$	Direct excreta urine and dung (de Klein *et al.* 2004)	0.01[A]; 0.01–0.02[B]; 0.0025[C]; 0.005[D]	0.01
$EF3_{AL}$	Direct effluent (pond treatment)	0.001	0.001
$EF3_{SS\&D}$	Direct solid waste and drylot	0.02	0.02
EF4	Indirect from volatilised N	0.01	0.01
EF5	Indirect from leached N	0.025	0.025
$FRAC_{GASM}$	Excreta volatilisation	Sum of volatilisation from all sources estimated in the model, except fertiliser	0.2 kg ammonia-N per kg of N excreted
$FRAC_{LEACH}$	Excreta leaching	Sum of leaching from all sources estimated in the model except fertiliser	0.075 kg nitrate-N per kg of N excreted
$FRAC_{GASF}$	Fertiliser volatilisation	Based on N fertiliser type, and adjusted for rainfall and soil type	0.1 kg ammonia-N per kg of fertiliser N applied
$FRAC_{LEACH}$	Fertiliser leaching	Based on N fertiliser type, and adjusted for rainfall and soil type	0.07 kg nitrate-N per kg of fertiliser N applied

[A]For sheep urine, and dairy and beef urine on free-draining soil.
[B]For dairy and beef urine, varies between 0.01 (free-draining soil) and 0.02 (poorly draining soil) depending on the drainage characteristics of the soil.
[C]For sheep dung.
[D]For dairy and beef dung.

(Source: Wheeler, et al., 2008)

2.4.2 OVERSEER Discussion

The greenhouse gas model was initially developed as a decision support tool for pastoral farmers to give an indication of their potential level and source of GHG emissions. It also gives a signal of the possible liability to be faced under an emissions trading scheme.

The GHG model differs from the national methane inventory in that it uses farm specific animal production, fertiliser, and pasture quality data. The national inventory incorporates average values for these inputs. For example, the national inventory assumes a fixed proportion of effluent is directed to anaerobic ponds, whereas on a farm either pond or spray systems are used. In addition, some factors are not available in the national inventory but are applicable to the farm scale, such as grazing-off.

In its current form, the model does not factor in carbon sinks or the contribution of changes in on-farm carbon stocks (soil, pasture, scrub or forest on-farm) to on-farm carbon emissions. Presently, the New Zealand national inventory also omits changes in on-farm carbon sinks, however forestry is included. An on-farm carbon budget which is similar to the nutrient budget could be added to the analysis (OVERSEER model) should demand be sufficient. To compare the size of an on-farm forestry sink required to absorb the equivalent amount of emissions, the model estimates the area of forest required, based on the rate at which different forest types absorb carbon dioxide.

There is a scenario evaluation setting within the model, for which mitigation options can be tested and compared. Methane mitigation options are centred on increasing animal efficiency, while nitrous oxide mitigation options include reducing nitrogen fertiliser use, substituting low protein supplements for fertiliser nitrogen boosted pasture, or winter grazing management options. These options also reduce nitrate leaching.

When comparing different farm scale models to estimate GHG emissions OVERSEER appears to be the most feasible model as it predicts methane emissions as per the national inventory, and extends the national inventory methodology for nitrous oxide. Other modelling substitutes that are available for use include DNDC (University of North Hampshire, 2009), Dexcel Whole Farm Dairy Model (DairyNZ, 2009), and EcoMod (Johnson, 2008) models. DNDC (DeNitrification DeComposition) is hampered by a lack of an animal component within the model. The Dexcel model fails to include a soil routine and is restricted solely to dairy cattle. EcoMod includes both an animal and soil component but is restricted to a single animal class at a time. In addition the EcoMod model is more of a research tool rather than an on-farm tool (URS, 2007). Overall, the OVERSEER nutrient budget and greenhouse gas model provides a holistic approach to farm scale assessment of management strategies on environmental losses, both through air and through the ground. The model is continuing to change and evolve as new information and research is created, and new mitigation strategies are developed (Wheeler, et al., 2008).

Reasons for employing OVERSEER can be summarised as:

- Already in use for nutrient budgeting
- Used widely by farmers around the country
- Easy to control

- Not data intensive
- Uses national inventory methods along with farm specific data
- More advanced compared to other models
- Calculates methane, carbon dioxide, and nitrous oxide emissions
- There is a possibility that it will be used for estimating emissions at the farm level once the ETS has been implemented

3 Methodology and data

3.1 Physical Methodology

The evaluation methodology uses regional representative farms to quantify the physical changes, such as production and animal numbers, from different greenhouse gas mitigation strategies for New Zealand farming. Dairy, and sheep and beef farming are considered since these are the two major greenhouse gas emitting agricultural industries. All other farming categories such as deer and equine are ignored. The greenhouse gas mitigation strategies to be evaluated are discussed later within this chapter. Dairy farming is split into six representative farms, while sheep and beef farming are split into 13 representative farms. A representative farm is calculated by regionally sampling between 20 and 60 actual farms in the region and calculating average physical characteristics. Each model is then augmented with feedback gathered from regional industry professional input and other information sources to best represent the current situation and expectations in each region. This augmentation is completed such that the representative farm is modelled on how a real farm would operate, as opposed to using an average of results from the monitored farms. All physical characteristics for each representative farm were obtained from P. Journeaux (personal communication, 21 May, 2008).

To quantify greenhouse gas emissions the OVERSEER farm model takes the physical characteristics of the representative farms and calculates the emission profiles based on physical inputs and outputs. The initial emissions profile of each representative farm is referred to as the „base case" emissions. The base year for dairy farming is 2007/08, while the base year for sheep and beef farming is 2006/07. OVERSEER is then used to evaluate and quantify the effects of mitigation strategies on physical characteristics and greenhouse gas emissions.

Physical results from implementing greenhouse gas mitigation strategies are displayed in tables in later sections. There are some factors that the farmer can alter in the short-run, whilst others are fixed. The main variables that the farmer can change are animal numbers and the level production, purchased feed, and nitrogen fertiliser inputs. Other factors such as effective area and soil characteristics are more difficult to change in the near term.

Changes in production are measured differently between dairy, and sheep and beef farming, where the former is quantified through milk solids and the latter through animal numbers. The OVERSEER model assumes that all sheep and beef stock units are the same size within the model. In reality, stock units will differ in size within any given herd.

Methane and nitrous oxide are both simultaneously emitted, and mitigation strategies affect both gases, so changes in these emissions are measured in CO_2 equivalents (CO_2-e). Furthermore, methane and nitrous oxide have higher global warming potentials than carbon dioxide. Global warming potential benchmarks greenhouse gases, relative to carbon dioxide which has a global warming potential of one. Methane has a global warming potential of 21, meaning that one methane molecule is equal to 21 carbon dioxide molecules. Nitrous oxide has a global warming potential of 310 (Clark, 2001).

Carbon dioxide emissions are not considered based on the assumption that this gas will be accounted for at off-farm points of obligation as per the Emissions Trading Scheme (ETS). Results are reported in absolute emission reductions and emission reductions as a percentage of base emissions. Both measures are used since animal numbers and the effective area of representative farms differ. This latter measure enables comparison between farms of different sizes.

There is an alternate measure of greenhouse gas mitigation, emissions per unit of output. This provides a different insight into the effects from greenhouse gas mitigation strategies. If policymakers decide to implement an alternate measure, other than total mitigation, then farmer behaviour could be different compared to a system that targets total mitigation. Scenarios that do not reduce total emissions are strictly not mitigation scenarios, but they are presented within the physical results to represent an alternative angle. As the Kyoto protocol and ETS focus on the absolute reduction in emissions, this is the main emissions target in this research.

As the scenarios are completed on a farm by farm basis, to gain a national picture each regional representative farm needs to be aggregated to gain a national total. There are two main options available for aggregating the regional dairy farm results; by using animal numbers, or land use dedicated to farming. Animal numbers are surveyed annually by the Livestock Improvement Corporation (2007) and land use dedicated to farming is drawn from A. Rae (personal communication, 7 September, 2008). Aggregating regional emissions based on land use holds farming intensity constant, therefore is preferred over animal numbers. Some of the sheep and beef regions have two representative farms to represent one geographical region. Therefore, the sheep and beef representative farms will be scaled by the number of "Farms Represented", shown in table 3.2. The aggregation methodology can be denoted mathematically as:

Dairy emission scaling

$$DE = \sum (E_i * N_j), \text{ and}$$
$$N_j = TA_j / EA_i$$

Where $i=j$, and;

DE = National dairy emissions,

E_i = Emissions for representative farm i,

N_j = Number of representative farms for region j,

TA_i = Total effective area in region j, and

EA_i = Effective area of representative farm i.

Sheep and beef emission scaling

$$S\&BE = \sum (E_i * FR_i)$$

Where;

S&BE = National sheep and beef emissions,

E_i = Emissions for representative farm i, and

FR_i = Farms represented by representative farm i, displayed in table 3.2.

By computing a national picture of emissions and costs associated with mitigation, national environmental policies can be examined along with their effects on the economy. Because the government has deferred finalising agriculture"s role in the ETS, the environmental policy examined within this study will follow the Kyoto protocol (reduce emissions to 1990 levels, equivalent to a 15.9 percent reduction from 2006). Farmers have the option of mitigating greenhouse gas emissions or purchasing carbon credits to meet emission targets. As these strategies are both acceptable, the purchase of carbon credits is examined where appropriate.

3.2 Financial Methodology

The financial methodology employs partial budgeting to assess the impact of greenhouse gas mitigation strategies on the profitability of farm level greenhouse gas emissions. Partial budgeting is a decision framework to compare the costs and benefits of alternatives faced by the farmer. It focuses on determining the income and cost changes from implementing a particular strategy. Therefore, other aspects of farm profits that are unchanged by the decision can be ignored (Roth, 2002). To ascertain the change in income and expenses, it is first necessary to quantify the change in physical characteristics stemming from the strategy.

Mitigation strategies affect farm inputs, and outputs, and their interaction, through complex channels. Often these numerous effects will positively affect some areas, and negatively affect others. Quantifying the overall effect from a single mitigation strategy requires the transformation of the physical effects into a single unit of account that can be compared across strategies and farms[3]. Price and cost information is used to transform the physical results into a single unit of account. The formula for calculating farm profitability is:

Farm profitability

$$\Delta P = (\sum p_j * y_j^+ + \sum p_i * x_i^-) - (\sum p_j * y_j^- + \sum p_i * x_i^+)$$

Where

ΔP = Change in farm profitability

p_j = price of output *j*

p_i = price of output *i*

y_j^+, x_i^- = Increase in output *j*, and decrease in input *i*, respectively, as a result of mitigation, and

y_j^-, x_i^+ = Decrease in output *j*, and increase in input *i*, respectively, as a result of mitigation.

[3] For example, one farm may reduce nitrogen fertiliser use and purchase additional feed, while another may build a feed pad. It is difficult to compare nitrogen fertiliser and additional feed to a feed pad. Therefore these physical transformations are converted into monetary values with price information, to enable comparisons across farms.

Quantity values are multiplied by price to attain revenue or cost changes. These were then summed over the categories where inputs and outputs were altered by the mitigation scenarios[4]. Partial budgeting isolates and quantifies total cost and benefit changes from the mitigation strategy.

Results are tabulated for each scenario using the following two categories; additional revenue/forgone costs, and additional costs/forgone revenue. This enables the examination of specific dollar value changes for all inputs and outputs that change. These along with physical emission reductions are used to quantify the cost per unit of mitigation.

Internationally-traded carbon credits are permits that allow businesses to emit additional carbon, so that they are able to meet environmental emission targets (as discussed in section 3.1). Carbon credits are standardised to a tonne of CO_2 equivalent emissions. The calculated measure, cost per ton of carbon dioxide equivalent mitigation, is analogous to the carbon credits measure. This calculates the cost to mitigate an additional tonne of carbon dioxide equivalent emissions. Purchasing carbon credits enables the user to emit an additional tonne of carbon dioxide equivalent emissions for a given price. Because these options are analogous when meeting emissions targets, the farmer can decide on appropriate actions between the two choices based on cost. If the carbon credit price is higher than the cost to mitigate an additional tonne, the farmer will be better off changing current farming practices to mitigate greenhouse gases, and vice-versa. Tables are presented to effectively display decision options.

The results will be reliant on the financial assumptions within the analysis. Large price changes from assumed values could affect the relative viability of strategies. In addition, some strategies will be more sensitive to price changes of particular inputs, and this may alter the ranking of strategies. As a result, different price assumptions are used to test the effect on results. It is essential for the dairy analysis where a historically high milk price is used within the price assumptions.

[4] For example, if there was an increase in production due to more rainfall on a dairy farm, then the change in physical production (measured in kgs of milk solids) is multiplied by the price (dollars per kg of milk solids) to calculate the total gain from the extra rainfall.

National financial results from greenhouse gas mitigation follow from the national physical aggregation methodology. Once farm level data has been scaled to the regional level, price assumptions are used to calculate the financial cost/benefit of adopting a mitigation scenario for the region. This cost can be compared to the regional financial liability of purchasing carbon credits from the open market, where no action is taken to mitigate greenhouse gases. Varying carbon credit prices are assessed to examine the financial liability on the region. Regional financial liabilities can be summed to attain the financial liability for each sector.

3.3 Data

3.3.1 Regional Production Data

OVERSEER is used to simulate a representative dairy farm for six regions in New Zealand to determine the physical effect of mitigation. The six dairy regions are; Northland, Waikato/Bay of Plenty, Taranaki, Lower North Island, Canterbury, and Southland. The sheep and beef sector is characterised by 13 different representative farms, although these are not based solely on geographical location. The 13 regions and farm types are: Northland, Waikato/Bay of Plenty intensive, Central North Island Hill Country, Gisborne Hill Country, Hawkes Bay/Wairarapa Hill Country, Eastern Lower NI Intensive, Western Lower NI Intensive, South Island Merino, Canterbury/Marlborough Hill Country, Canterbury/Marlborough Breeding and finishing, Otago Dry Hill, Southland/South Otago Hill Country, Southland/South Otago Intensive. Intra-region variability for the sheep and beef sector implies a greater number of representative farms, to symbolise the regional farming situation.

Table 3.1: Selected summary production and physical characteristics for each dairy representative farm (2007/08)

	Farms Represented	Farms Contributing	Effective Area (ha)	Base Production (kg/MS)	Base Case Cow Numbers
Northland	1,200	25	108	64,800	244
Waikato/BOP	5,140	50	103	95,900	292
Taranaki	1,800	26	96	87,900	265
LNI	1,080	28	130	114,400	360
Canterbury	770	30	203	268,708	682
Southland	660	30	208	196,000	490

(Source: Ministry of Agriculture and Forestry, 2008)

Table 3.1 represents key physical characteristics for each representative dairy farm. „Farms represented" is the number of dairy farms that each representative farm from each region represents, with over 10,000 farms nationwide. Base dairy production from representative each farm is measured in terms of milk solids, and assessed through the number of cows in each region.

Table 3.2: Selected summary production and physical characteristics for each sheep and beef representative farm (2006/07)

	Farms Represented	Effective Area (ha)	Base Case Sheep Numbers	Base Case Cattle Numbers
Northland	980	314	785	2,367
Waikato/Bay of Plenty intensive	1055	250	1,393	1,413
Central North Island Hill Country	2,220	635	3,414	2,002
Gisborne Hill Country	605	821	4,041	3,429
Hawkes Bay/Wairarapa Hill Country	1,165	624	4,343	1,635
Eastern Lower NI Intensive	805	347	2,450	1,620
Western Lower NI Intensive	420	208	1,620	838
South Island Merino	220	10,508	7,614	1,400
Canterbury/Marlborough Hill Country	425	1397	3,431	1,952
Canterbury/Marlborough Breeding and finishing	1,650	378	2,877	808
Otago Dry Hill	400	2,000	5,654	870
Southland/South Otago Hill Country	720	723	5,203	817
Southland/South Otago Intensive	1,700	194	2,556	135

(Source: Ministry of Agriculture and Forestry, 2007)

Table 3.2 shows sheep and beef farm characteristics for the representative sheep and beef farms. The sheep numbers are taken from the "opening sheep stock units" for 2006/07. Likewise, the cattle numbers were taken from the opening cattle stock (Ministry of Agriculture and Forestry, 2007). Nationally, over 12,000 sheep and beef farms are represented, with an un-weighted average effective area of 1,415 ha. The majority of dairy representative farms have an effective area of approximately 100ha, with the largest being Southland with an effective area of over 200ha. The sheep and beef sector is typically characterised by low stocking rates over a large effective area. This contrasts with the dairy sector which is characterised by high stocking rates over a small effective area.

3.3.2 Costs and Prices

In addition to physical characteristics, a financial balance sheet is provided for each model farm (dairy 2007/08, and sheep and beef 2006/07). Figures for the balance sheet are averaged from the contributing farms, and then professional user judgement is used to create a balance sheet that is similar to a real working farm. This is opposed to simply taking an average across sampled farms. This methodology is similar to the physical data. Financial balance sheets for all representative farms are taken from the monitoring reports published by Ministry of Agriculture and Forestry (2008).

There also needs to be an associated monetary cost to implement mitigation strategies. Inevitably, these prices (costs) will vary between regions and between product suppliers within regions. Therefore, regional data on prices are used when available, otherwise national prices are is used in place of regional prices. The prices for the majority of farms are obtained from the *Financial Budget Manual* (*Financial budget manual*, 2008) published yearly by Lincoln University. Prices drawn from this manual included; fertiliser spreading costs, supplements, feed pads, and wintering/stand-off pads. Information on the price of DCD (Eco-n) and nitrogen fertilisers are drawn from the Ravensdown price list for 2008 (Ravensdown, 2008). In addition, fertiliser price information is also available from Ballance (Ballance, 2008).

Specific price assumptions and sources used within the modelling are listed below;

- Milk solid price, $7.43 per kg/MS for 2008. Price data is taken from the monitoring reports published by Ministry of Agriculture and Forestry (2008).

- Maize silage (used to replace nitrogen boosted pasture) 15 cents per kg DM, drawn from the *Financial Budget Manual* (2008), and was the actual price paid in 2006/07.
- Fertiliser costs (urea) $1,250 per tonne of raw material. Both Ravensdown (2008) and Ballance (2008) had similar prices in 2008.
- Eco-n cost $79 applied per hectare, as per the Ravensdown (2008) price list.
- Feed and wintering pads are assumed to cost $150 per cow for construction. DairyNZ (2008a, as cited by *Financial Budget Manual,* 2008) state that a concrete feed pad will cost up to $125 per cow for a 200 cow herd. They state that there is significant variability between contractors and that more than one quote should be obtained. As there is greater variability $150 per cow is used to construct both feed and wintering pads.
- DairyNZ (2008a) also state that maintenance costs are likely to be a maximum of $10 per cow per annum, which is used in this study.
- Interest rate used for the capital costs is assumed to be the base lending rate taken from the Reserve Bank of New Zealand (2008). "The base interest rate offered to new business borrowers, weighted by each surveyed institution"s total NZ dollar claims" (Reserve Bank of New Zealand, 2008). The rate used is 13.79 percent from October 2008.

Fonterra"s payout was used for all farms as part of their revenue, where the latest payout was used ($7.43 per kg of milk solids). The high payout is not expected to last into the future; therefore sensitivity analysis is used to test the implications of this assumption.

The assumptions used within the model regarding prices were taken from academic and industry sources. Sheep and beef meat prices are not shown above, because production is measured in hypothetical stock units. OVERSEER provides production changes in both stock units and as a percentage increase. For simplicity, the percentage increase in production is used to calculate the change in revenue. Mathematically;

Sheep and beef change in revenue

$$\Delta R_i = \%\Delta Q_i * R_i$$

Where

ΔR_i = Change in revenue for representative farm *i*,

$\%\Delta Q_i$ = Percentage change in production (measured as stock units) for representative farm *i*, and

R_i = Base revenue for representative farm *i*, as at 2006/07.

3.3.3 Other Data Requirements

Farm-level emissions data will need to be scaled up to provide a regional and then national emissions profile. As discussed previously, scaling by effective area (i.e. the amount of land dedicated to either dairy of sheep and beef farming activities in each region) is used. Land use data is obtained from A. Rae (personal communication, 7 September, 2008). The data is disaggregated according to the type of farming.

3.4 Mitigation Strategies Simulated with OVERSEER

Modelling a farming system is complicated with many different inter-related variables interacting and affecting each other. Mitigation strategies generally affect both nitrous oxide and methane gases. For example, reducing nitrogen fertiliser use is primarily aimed at reducing nitrous oxide emissions, but as this strategy may also cause animal numbers to reduce and therefore methane emissions reduce due to fewer animals being held on farm. Selected strategies, outlined in the literature review, are not examined quantitatively within this study. Some of these strategies are scientifically unproven and are not readily available for farmers to implement at the farm level. Therefore, only available and proven strategies are examined further. One scenario not examined in this research, is solely reducing animal numbers, to mitigate emissions[5]. The strategies are categorised based on whether they primarily target methane or nitrous oxide emissions. Nitrous oxide mitigation strategies are examined first, followed by methane mitigation strategies.

3.4.1 Nitrous Oxide Mitigation Scenarios

Reduced Nitrogen Fertiliser Use

One of the major sources of nitrous oxide is from nitrogen fertiliser application, where there is a direct positive relationship between the amount of nitrogen fertiliser applied and the level of nitrous oxide emissions. Therefore by reducing nitrogen fertiliser use (less nitrogen on pasture) nitrous oxide emissions will decrease *ceteris paribus*. The first scenario run through OVERSEER is a 50 percent reduction in nitrogen fertiliser applied to pasture. This leads to an associated reduction in animal numbers and a

[5] The model translates a 10 percent reduction in animal numbers into a 10 percent reduction in production, and hence a 10 percent reduction in revenue. For example, a 10 percent reduction in animal numbers represents a loss in revenue of $71,253 the Waikato representative farm, from the base case. If there is a large cost for carbon credits then farmers might be able to profit by selling carbon credits gained from reducing animal numbers. An environment that promotes these actions would be disadvantageous to all emitting industries as there are more cost effective ways to reduce emissions, that could also meet environmental targets.

decrease in production along with overall on-farm emissions. There are other fertiliser methods which the farmer can undertake including timing and matching the nitrogen demand for the pasture, but these options are not simulated in this research.

Financial benefits: There are benefits associated with reducing nitrogen fertiliser use, including reduced fertiliser costs, animal health, and production costs. As the farmer requires less fertiliser, raw material costs fall accordingly. In addition, costs associated with fertiliser spreading will fall but the magnitude is unclear. Since other fertilisers that do not contain any nitrogen are still applied onto the farm, it is difficult to separate nitrogen fertiliser spreading costs from spreading costs that do not contain nitrogen. Therefore, spreading cost savings are assumed to be zero.

With fewer animals held on the farm there will be savings associated with; labour, animal health, breeding, and dairy shed expenses. Because allocating a farmer‟s time between activities is difficult, these labour savings are assumed to be zero. The benefits considered in this research are reduced fertiliser spending, diminished animal production costs, reduced animal health, breeding and dairy shed costs.

Financial costs: As animal numbers decline so does farm revenue, since there are fewer productive animals held on farm. Reduced farm revenue is the only financial cost considered with this scenario.

Zero Nitrogen Fertiliser Use

The second scenario examines the effect of applying no nitrogen fertiliser to the farm, which is an extension of the first nitrogen scenario. By adding no nitrogen for plant growth the nitrogen held within the system will need to be managed, or replaced in other ways, by the farmer (such as nitrogen fixing by clover). Ruminant animals require little nitrogen for production.

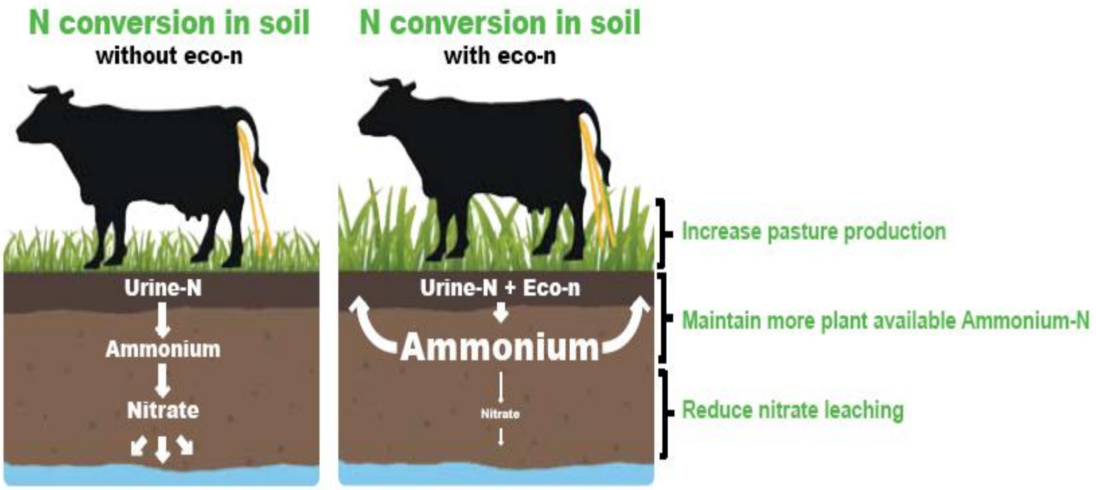
Financial benefits: Similar benefits are attained as per the first scenario, however on a greater scale. The benefits considered in this scenario are reduced fertiliser spending, diminished animal production costs, reduced animal health, breeding and dairy shed costs.

Financial costs: Costs of reducing nitrogen fertiliser use to zero will be lost production, as there are fewer animals held on the farm. The intensity of the farming operations will also fall as there are fewer animals on the same amount of land compared to before. The longer-term impact of applying no nitrogen fertiliser is recognised by OVERSEER, and in the absence of nitrogen fixing plants (such as clover) a nitrogen fertiliser application may be required eventually.

DCD Application

A key mitigation strategy is the use of nitrification inhibitors to reduce nitrous oxide emissions. DCD works by improving nitrogen cycling in the soil of grazed dairy pasture, and is the most well known direct inhibitor of nitrous oxide. It is commercially known as Eco-n. This third scenario assumes that DCD (Eco-n) is used on the whole farm with the aim of mitigating nitrous oxide emissions. There are 5 requirements which the farmer must satisfy for DCD to work effectively as assumed in OVERSEER. These are: DCD is applied to pasture (fodder crops and crops are excluded from the model); the effective rate of DCD is 10 kg/ha/application; DCD is applied within seven days of grazing; there are two applications of DCD per year (in April/May and July/August); and DCD product is applied according to supplier‟s specifications. If these conditions are not met then the user is not able to state that they use DCD within the OVERSEER model.

Figure 3.1: Effect of Eco-n on Pasture Production



(Source: Ravensdown, 2008)

Financial benefits: These include additional pasture growth leading to greater animal production. With additional pasture available for consumption production can increase. As Eco-n reduces the loss of nitrogen to competing sources, nitrogen fertiliser use can simultaneously decline as less nitrogen is needed. Reducing nitrogen fertiliser use combined with Eco-n simultaneously is not examined in this research.

Financial costs: There is a cost associated with purchasing and spreading DCD on the farm. The price given from Ravensdown is the "applied per hectare" cost of DCD. If animal production is simultaneously increased with the application of Eco-n, then production costs associated with holding additional animals will increase.

Substitute Supplements for Nitrogen

A significant downfall of applying no nitrogen fertiliser to pasture is that production falls as the pasture cannot support the original number of stock units. Hence, to keep production constant farmers can import additional feed to keep production constant. In this scenario, supplementary feed is purchased such that the metabolisable energy (ME) consumed remains the same as before when nitrogen was applied to boost pasture production. Therefore, in this case there is no nitrogen fertiliser applied to the pasture but production remains constant. The additional feed is distributed onto paddocks.

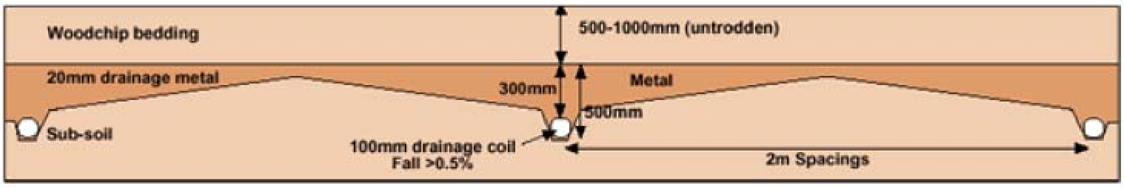
Financial benefits: Include no nitrogen fertiliser costs. Benefits under this scenario will be similar to the zero nitrogen fertiliser scenario; however production remains constant negating any herd size savings.

Financial costs: The only additional cost is to purchase and distribute feed such that ME remains constant. Explicit distribution costs are ignored because they are difficult to accurately quantify.

Reduced Winter Grazing

The major source of nitrous oxide emissions come from animals excreting and urinating nitrogen onto pasture. The less time they spend directly on pasture fewer faeces will be deposited, hence reducing emissions. In this scenario animals are taken off pasture for winter months and are placed on a winter pad and fed supplements which are low in nitrogen content (such as maize). The animals are placed on the winter pad for the winter months, and during these months are still grazed for 5 hours a day. The pad surface has an inert lining. The solids that are gathered from the winter pad are spread over the whole farm and are not stored. Maize supplements are purchased and are fed to the animals while on the winter pad. Since no nitrogen is applied in this scenario, supplements are imported to keep ME and production constant.

Figure 3.2: Cross section of a typical stand-off pad



(Source: DairyNZ, 2008b)

The pads are constructed with a top layering of woodchip for animal comfort and sanitation. Drainage metal is used to support the upper layer and provide stability for the concrete design that is fixed to the ground. Concrete design follows the “[h]ump and hollow drainage with subsurface drains laid in hollows and covered with permeable backfill will drain the pad” (DairyNZ, 2008b, p.1).

Financial benefits: The financial benefits include no nitrogen fertiliser costs. Also, there could be some positive benefits if the wintering pad improves farm efficiency in terms of stock management, or if combined with another strategy that improves production such as increasing feed intake (and feeding it on the wintering pad). However, the only benefit considered from the reduced winter grazing scenario is zero nitrogen fertiliser use.

Financial costs: The costs associated with this scenario are similar to the previous scenario, but with the added cost of constructing and maintaining a wintering pad. The construction costs are annualised over a life span of 30 years productive life, using the base lending rate as the discount rate. To keep the wintering pad productive maintenance is also required. Costs explicitly considered include; additional purchased maize, annualised construction costs, and yearly maintenance costs of the wintering pad.

Ultimate Nitrogen Strategy

This strategy combines the reduced winter grazing strategy and the DCD scenario, to provide the maximum reduction in emissions based on a combination of nitrogen mitigation strategies. This scenario is not used for sheep and beef farmers.

Financial benefits: The financial benefit of this strategy is zero nitrogen fertiliser costs. Reduced fertiliser spreading costs are assumed to be zero.

Financial costs: The additional costs associated with the ultimate nitrogen mitigation strategy are a combination of the DCD and reduced winter grazing scenarios. These include; DCD application and raw material costs, imported feed costs, annualised wintering pad construction costs, and maintenance costs of the wintering pad. Animal numbers are held constant in this scenario.

3.4.2 Methane Mitigation Scenarios

Increasing Feed Intake

In the short term, increasing production per animal is a widely recognised way to reduce methane emissions. Adding extra feed to animals on top of current feeding levels is one way to increase production per animal, thereby diluting emissions measured as emissions per unit of output. However, this strictly is not a mitigation strategy as increasing feed intake for animals will increase total emissions if animal numbers are held constant (holding animal numbers constant is not considered as a scenario). This scenario is examined to assess the impact on emissions per unit of output. Within the OVERSEER model, animal numbers (stock units) increase for both dairy and sheep and beef farming. For dairy, maize will be added to the diet at a rate of 200, 300, and 400 kg/year per cow. Sheep and beef rates are 100, 200, and 300kg per animal (P. Journeaux, personal communication, 21 May, 2008). Extra feed is fed out on paddocks.

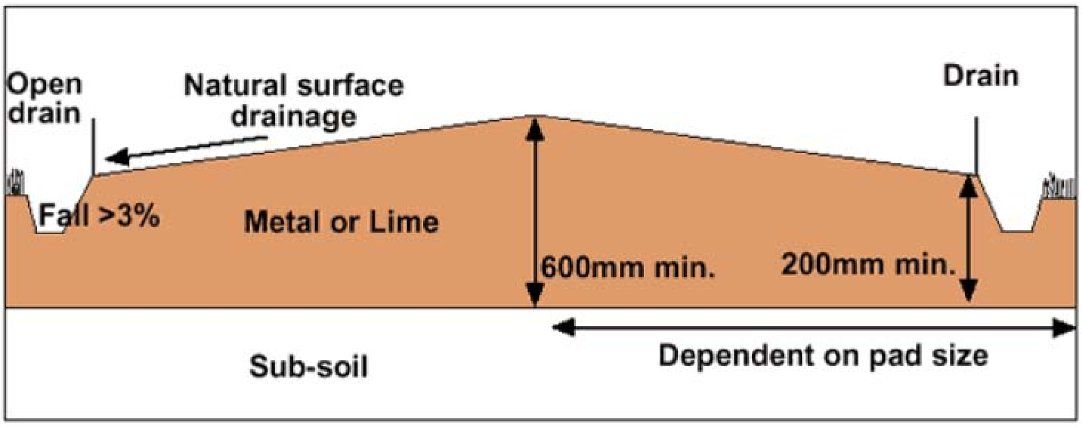
Financial benefits: The financial benefit associated with increasing feed intake is increased production. For dairy farms this is increased milk solids production, and for sheep and beef this is increased animal numbers. Quality of extra output is assumed to be constant.

Financial costs: Distribution and purchased feed are the two major costs associated with this strategy. Purchased feed costs are considered, whilst distribution costs are ignored. Also, the production and animal health expenses associated with an increase in stock units are calculated.

Replace Roughage with Concentrate

Eating lower quality feed, such as pasture, produces more methane than high concentrate feeds such as grains. By substituting pasture with higher concentrated feed farmers are able to reduce methane emissions. In the New Zealand farming situation, the lower quality feed is nitrogen-boosted pasture production, therefore by replacing nitrogen-boosted pasture with high quality grains methane and nitrous oxide emissions will be reduced. The additional feed is distributed on a feed pad during milking time. Hence the cows spend a relatively similar amount of time on pasture compared to the status quo. This offers a more convenient form of administering the extra feed. Sheep and beef animals are unable to use feed pads.

Figure 3.3: Cross section of a feed pad



(Source: DairyNZ, 2008a)

Typically, concrete feed pads are four to five meters wide and are required to be 110mm thick if only stock will be placed on the pad, and 125mm thick and reinforced if machinery will also have access. The pad is sloped to prevent water gathering on the feed pad with the slope being greater than 3 percent (DairyNZ, 2008a).

Financial benefits: Reduced fertiliser costs are the only considered financial benefit from implementing this strategy. There could be some efficiency gains from the feed pad, however these are not considered as they cannot be quantified.

Financial costs: The costs associated with this scenario are the annualised construction costs, maintenance costs, and feed costs. The construction costs of the feed pad are spread over the useful productive life of the feed pad (30 years). The base lending rate is used as the discount rate. Maintenance costs are based on a per cow basis, as sheep are unable to use a feed pad.

Productivity Gains

Not all productivity gains have been exhausted by many farmers. In this scenario, the farmer achieves a gain in output (the source of the gain is unknown), whereby the farmer is able to achieve a reduction in the number of cows with production held constant from the base case. For example, 100 cows currently produce 200 kg of milk solids per year when the farmer implements a productivity improvement. Now the herd is only 90 cows but production is still 200 kg milk solids per year, meaning that each cow now has a higher yield. The source of the increase in productivity is unknown. Furthermore, this necessitates assuming a costless productivity gain. Reductions of cow numbers examined are 5, 10, and 15 percent respectively. This scenario was not used for sheep and beef farms as it is technically impossible to hold output constant and reduce animal numbers in OVERSEER.

Financial benefits: By increasing the efficiency of the herd, the only gain is in holding a smaller herd, as production does not change.

Financial costs: The strategy does not explicitly state any costs, but will depend on what the farmer decides to implement to improve productivity. As costs are unknown under this scenario only the farmer‟s reservation price of the scenario is known.

Ultimate Methane Mitigation Scenario

This scenario combines two methane mitigation strategies, a 15 percent productivity gain and replacing roughage with concentrate scenario. This scenario is used for dairy only.

Financial benefits: The gains associated with this mitigation strategy include zero distribution and raw material costs of nitrogen fertiliser, and the benefit of holding a smaller herd.

Financial costs: As this scenario contains unknown productivity gains, the costs are unable to be quantified.

3.4.3 Scenario summary

Notation is used to signify different management strategies, where there are three parts. Firstly management scenarios run on a dairy farm are denoted with a D, and sheep and beef farms are denoted with S&B. Secondly, ME refers to strategies that primarily target methane emissions, and NO refers to strategies that target nitrous oxide. Finally the number refers to the different scenarios within the particular category.

Management strategies are split into two different categories. The first category aims at reducing emissions per unit of output but overall net emissions increase. This subset is presented only in the physical results for reasons discussed earlier. These are scenarios DME1-3 and S&BME3-5.The second category targets reducing total emissions, as per the ETS and Kyoto protocol.

Dairy

The dairy management strategies analysed are[6]:

DME1: Increase feed intake by 200kg per animal per year. Additional feed is maize silage.

DME2: Increase feed intake by 300kg per animal per year. Additional feed is maize silage.

DME3: Increase feed intake by 400kg per animal per year. Additional feed is maize silage.

DME4: Zero nitrogen fertiliser use, combined with increasing maize silage such that production, and metabolisable energy, remains constant from the base case. The additional maize silage is distributed on a feed pad.

DME5: Animal numbers are cut by 5 percent while keeping production constant, creating 5 percent productivity gain. The source of the gain in efficiency is unknown.

DME6: Animal numbers are cut by 10 percent while keeping production constant, creating 10 percent productivity gain. The source of the gain in efficiency is unknown.

[6] Reducing cow numbers are not considered as a mitigation strategy, as discussed previously.

DME7: Animal numbers are cut by 15 percent while keeping production constant, creating 15 percent productivity gain. The source of the gain in efficiency is unknown.
DME8: The combined strategies of DME4 and DME7.

DNO1: Reduce nitrogen fertiliser use by 50 percent from the base.
DNO2: Reduce nitrogen fertiliser use to zero.
DNO3: Apply DCD.
DNO4: Reduce fertiliser use to zero, and then maize silage is purchased to keep production, and metabolisable energy, constant compared to the base case. Additional feed is distributed onto paddocks. Where the feed is distributed is the main difference between this strategy and DME4.
DNO5: Equal to DNO4, but with the addition of a wintering or stand-off pad. The animals are allowed to graze 5 hours per day over winter months and maize silage is fed onto the wintering pad.
DNO6: Combined DNO3 and DNO5 strategies.

Sheep and Beef

The sheep and beef management strategies analysed are[7]:

S&BME1: Reduce fertiliser use to zero and import maize grains to keep production, and metabolisable energy, constant from the base case. Additional maize grain is fed onto paddocks.
S&BME2: The same as S&BME1, but with the addition of a wintering/stand-off pad. Cattle are allowed to graze 5h per day over winter months and maize is fed onto the wintering/stand-off pad. Only cattle are able to use the wintering pad.
S&BME3: Increase feed intake by 100kg per animal per year.
S&BME4: Increase feed intake by 200kg per animal per year.
S&BME5: Increase feed intake by 300kg per animal per year.
S&BNO1: Reduce nitrogen fertiliser use by 50 percent from the base.
S&BNO2: Reduce nitrogen fertiliser use to zero.
S&BNO3: Apply DCD.

[7] Reducing sheep or beef numbers are not considered as a mitigation strategy, as discussed previously.

4 Results

There are three sections presented within the results chapter. The first section examines how physical characteristics, such as animal numbers, output and inputs, and greenhouse gas emissions change as a result of the mitigation strategies implemented. The second section investigates the financial cost/benefits, and change in profit, of these physical changes. Also the cost per unit of emissions mitigated is calculated, along with the sensitivity analysis. Finally, the regional and national results, and the cost/benefit of agriculture meeting Kyoto emission targets, are investigated.

4.1 Effects on Physical Characteristics

Implementing management strategies to mitigate greenhouse gas emissions will affect inputs and outputs at the farm level. In general, the main output that is affected is production, namely milk solids for dairy farming, and animal numbers for sheep and beef. This section presents the magnitude and direction of the change in inputs and outputs, in response to the mitigation strategies, for the dairy sector followed by the sheep and beef sector. The main focus of this section is the impact on greenhouse gases.

4.1.1 Dairy sector

As discussed earlier, the mitigation scenarios examined are broadly grouped into those that primarily target reducing methane emissions, and those that primarily target reducing nitrous oxide emissions. However, the farming system is complex with many different variables affecting each other. Hence, it is impossible to completely separate the effects of the scenarios to solely methane or nitrous oxide emissions. For this reason results presented are standardised to carbon dioxide equivalents, and account for changes in methane and nitrous oxide. The table below examines whether methane or nitrous oxide gases are affected by the mitigation scenarios.

Table 4.1: Dairy farming mitigation scenario effects, on methane and nitrous oxide emissions

	Reduce methane emissions?	Reduce nitrous oxide emissions?
DME1	No	No
DME2	No	No
DME3	No	No
DME4	Yes	Yes
DME5	Yes	Yes
DME6	Yes	Yes
DME7	Yes	Yes
DME8	Yes	Yes
DNO1	Yes	Yes
DNO2	Yes	Yes
DNO3	No	Yes
DNO4	Yes	Yes
DNO5	Yes	Yes
DNO6	Yes	Yes

The effects presented in Table 4.1 hold for all representative dairy farms. Of the mitigation strategies, only scenarios DME1-3 do not reduce greenhouse gas emissions. They in fact, increase emissions, but also alter emissions per unit of output compared to the base case. All other strategies reduce total greenhouse gas emissions. The main channel methane mitigation scenarios affect nitrous oxide emissions is through lower animal numbers, spending less time on pasture, and eating higher quality feed. Within the nitrous oxide strategies only DNO3 does not simultaneously lower nitrous oxide and methane emissions. In fact, this scenario keeps methane emissions constant. The main channel through which nitrous oxide scenarios affect methane emissions is by lower numbers and higher quality feed.

Below are two tables that show how selected physical attributes of a representative farm change once mitigation strategies are implemented. The Waikato/BOP dairy representative farm is used to examine how these physical characteristics are affected due the mitigation scenarios. The other five representative farm results are presented in the appendix. A specific outline of what the various scenarios represent can be found in the methodology chapter, while base case refers to the initial farming situation (also outlined in the methodology chapter). Milk solids, nitrogen fertiliser, and purchased feed are measured in tons.

Table 4.2: Farm level impacts from methane scenarios, for the Waikato/BOP dairy representative farm (2007/08)

	Base Case	DME1	DME2	DME3	DME4	DME5	DME6	DME7	DME8
Milk solids (t)	95.9	97.3	98.6	100	95.9	95.9	95.9	95.9	95.9
Cow numbers	292	308	324	340	292	277	263	248	248
Nitrogen fertiliser (t)	13.8	13.8	13.8	13.8	0	13.8	13.8	13.8	0
Purchased feed (t)	0	61.6	97.2	136	75	0	0	0	75
Methane emissions (tons of CO_2-e)	620	647	664	681	400	603	587	570	351
Nitrous oxide emissions (tons of CO_2-e)	339	340	341	343	120	329	321	312	94

Table 4.3: Farm level impacts from nitrous oxide scenarios, for the Waikato/BOP dairy representative farm (2007/08)

	Base Case	DNO1	DNO2	DNO3	DNO4	DNO5	DNO6
Milk solids (t)	95.9	92.2	89.2	95.9	95.9	95.9	95.9
Cow numbers	292	282	271	292	292	292	292
Nitrogen fertiliser (t)	13.8	6.9	0	13.8	0	0	0
Purchased feed (t)	0	0	0	0	75	75	75
Methane emissions (tons of CO_2-e)	620	598	575	620	425	405	426
Nitrous oxide emissions (tons of CO_2-e)	339	289	239	298	137	146	151

Tables 4.2 and 4.3 represent changes in selected farm variables that are affected by the mitigation scenarios. The viability of the representative farm to support agricultural animals varies as a result of management decisions. When nitrogen fertiliser usage is reduced (DNO1 and DNO2) without any compensating measures undertaken, animal numbers and production fall accordingly. This is a direct result of less pasture growth to support the base case animal population. If the farmer decides to keep dairy production constant from the base case while applying no nitrogen fertiliser (DNO4), 75 tons of maize silage would be needed to keep metabolisable energy constant, for the Waikato/BOP representative farm. Therefore the decision to purchase maize feed (75 tons) or apply nitrogen fertiliser (13.8 tons) is equal in terms of production. Alternatively by purchasing additional maize feed (more than 61.6 tons) the farmer can support more animals on the farm (DME1-3). The effects on greenhouse gas emissions from the individual mitigation strategies, for all representative farms, are presented below.

Figure 4.1: Mitigation of greenhouse gas emissions for each dairy representative farm (tons of CO2-e, 2007/08)

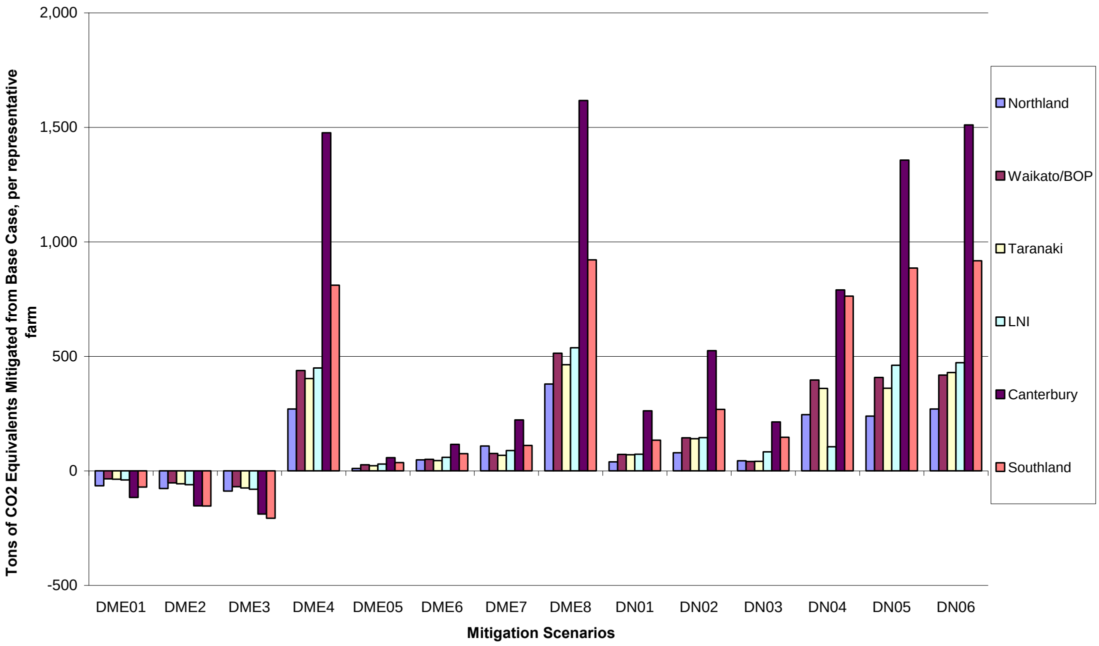


Figure 4.1 displays the emission reductions from the base case for each dairy representative farm. Each individual scenario is investigated independently of all other scenarios, and is measured in CO_2-equivalents (CO_2-e). Mitigation strategies DME1, DME2, and DME3 all involve increasing feed intake and therefore raise both emissions and production[8].

The Canterbury dairy representative farm has the largest reduction in emissions while the Northland representative farm has the lowest reduction in emissions. This is a result of Canterbury‟s significant size advantage with over 600 dairy cows compared to Northland‟s 244. Canterbury is the most intensive representative farm. Scenario DME8 has the greatest impact on greenhouse gas emissions, where Canterbury reduces total emissions by over 1,600 tons of CO_2-e. DME4 also has a large impact. As the farms are different in terms of effective area and animal numbers it is more

[8] The reason for this scenario simulation is that the farmer can profit from low carbon prices, when the benefit from additional production is high. For example, if the farmer faces a marginal cost and marginal benefit of $30 and $100 of production respectively, to emit an extra tonne of CO_2 emissions, the farmer can obtain a net gain of $70. Increasing emissions will continue until marginal benefit equals marginal cost. The farmer may not be currently implementing these profitable due to barriers to entry for the scenario.

appropriate to compare results as a percentage of base case emissions, to account for these initial differences.

Figure 4.2: Mitigation of greenhouse gas emissions for each dairy representative farm, expressed as a percentage of base case emissions (2007/08)

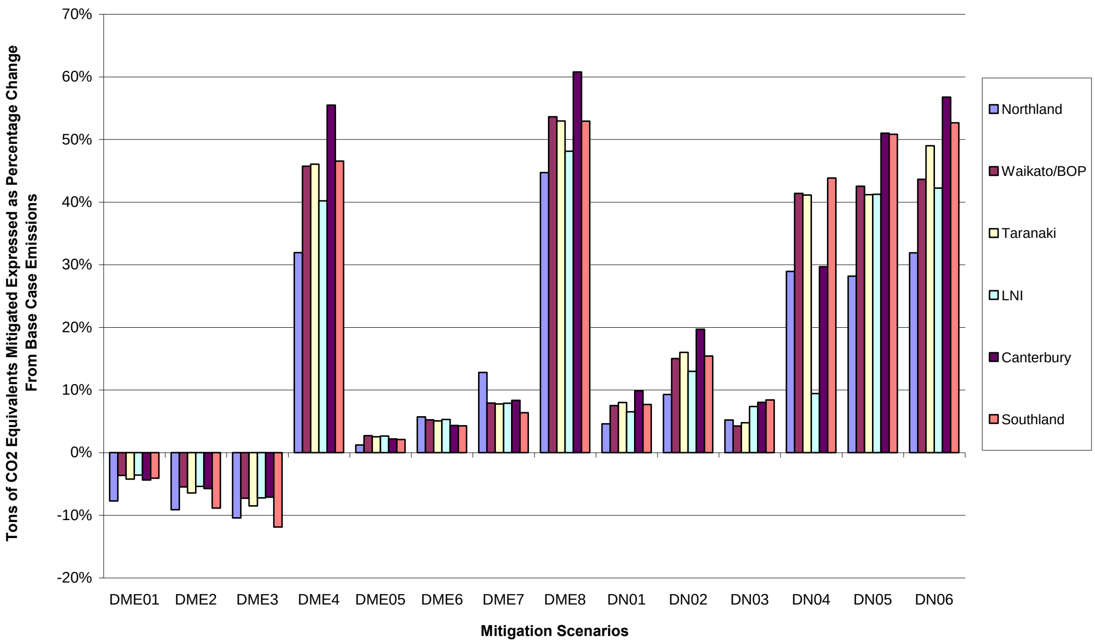


Figure 4.2 displays emission reductions expressed as a percentage change from base case emissions, making mitigation scenarios comparable between farms. It is interesting to note that the relative effect on emissions (from base case) is different between regions. For example, Northland has a particularly strong effect from scenario DME7 compared to other regions, because the cows are initially underutilised (resulting in increased emissions associated with maintenance) when compared to other regions. This shows that other factors alter the mitigation effectiveness of a single scenario between regions, and this requires examination at the farm level first and foremost. Again DME8 has the greatest proportional impact on emissions with Canterbury achieving the greatest reduction due to the high level of base case intensity.

4.1.2 Sheep & Beef sector

As discussed above in the dairy section, farming is a complex system and separating mitigation strategies that affect solely one gas is very difficult. Therefore, the table below examines whether methane or nitrous oxide gases are affected by the mitigation scenarios.

Table 4.4: Sheep and beef farming mitigation scenario effects, on methane and nitrous oxide emissions

	Reduce methane emissions?	**Reduce nitrous oxide emissions?**
S&BME1	Yes	Yes
S&BME2	Yes	Yes
S&BME3	No	No
S&BME4	No	No
S&BME5	No	No
S&BNO1	Yes	Yes
S&BNO2	Yes	Yes
S&BNO3	No	Yes

Fewer management mitigation strategies are available to sheep and beef farmers because sheep are unable to use feed or wintering pads. Similarly, within OVERSEER productivity gains for the sheep and beef sector are measured as changes in stock units, thereby disabling productivity gains for sheep and beef farming. By definition it is impossible to reduce animal numbers while achieving a gain in output, measured as a gain in animal numbers. The mitigation scenarios that do not reduce total emissions (but instead target emissions per unit of output) are S&BME3-5. These are analogous to scenarios DME1-3 discussed previously. Scenario S&BNO3 is the only other scenario that does not reduce both methane and nitrous oxide gases, since DCD application does not reduce methane emissions. The main effect on nitrous oxide emissions from the methane mitigation scenarios is through better quality feed. Alternatively, the main effect on methane emissions from nitrous oxide scenarios is through reduced animal numbers.

The sheep and beef sector is different from the dairy sector in terms of intensity and effective area. The dairy sector is characterised by a small effective area and high intensity (with respect to stocking rates), whilst the sheep and beef sector is characterised by a large effective area and low intensity (with respect to stocking rates). The Waikato/BOP sheep and beef farm is used to characterise selected physical results, with other representative farm results presented in the appendix. The specific outline of what the scenario abbreviations signify can be found in the methodology and data chapter, along with the dairy abbreviations.

Table 4.5: Methane and nitrous oxide scenario farm level impacts for the Waikato/BOP sheep and beef representative farm (2006/07)

	Base Case	S&B ME1	S&B ME2	S&B ME3	S&B ME4	S&B ME5	S&B NO1	S&B NO2	S&B NO3
Production change (%)		0.0	0.0	24.0	48.0	72.0	-0.3	-0.6	2.3
Cattle numbers	1413	1413	1413	1752	2091	2430	1409	1405	1445
Sheep numbers	1393	1393	1393	1727	2062	2396	1389	1385	1425
Nitrogen fertiliser (t)	1.2	0	0	1.2	1.2	1.2	0.6	0	1.2
Purchased feed (t)	0	7	7	281	561	842	0	0	0
Methane emissions (tons of CO2-e)	700	682	681	845	990	1040	698	696	716
Nitrous oxide emissions (tons of CO2-e)	280	265	264	312	344	374	276	272	234

Scenarios analysed for the sheep and beef sector have more muted effects on production and inputs. Scenarios S&BME3-5 have the largest impact as purchased maize feed is increased. But production similarly increases along with the additional maize feed the farmer purchases. For example, under S&BME5 production increases 72 percent compared to the base case for the Waikato/BOP representative farm. Apart from this group of strategies, production is little changed for other scenarios. The level of nitrogen fertiliser used on the Waikato/BOP representative farm is only 1.2 tons, relative to its effective area of 250 hectares. Therefore reducing the use of nitrogen fertiliser is a limited mitigation strategy since little nitrogen fertiliser is used in the base case. Emissions results for the 13 sheep and beef representative farms are presented below.

Figure 4.3: Mitigation of greenhouse gas emissions for each North Island sheep and beef representative farm (tons of CO2-e, 2006/07)

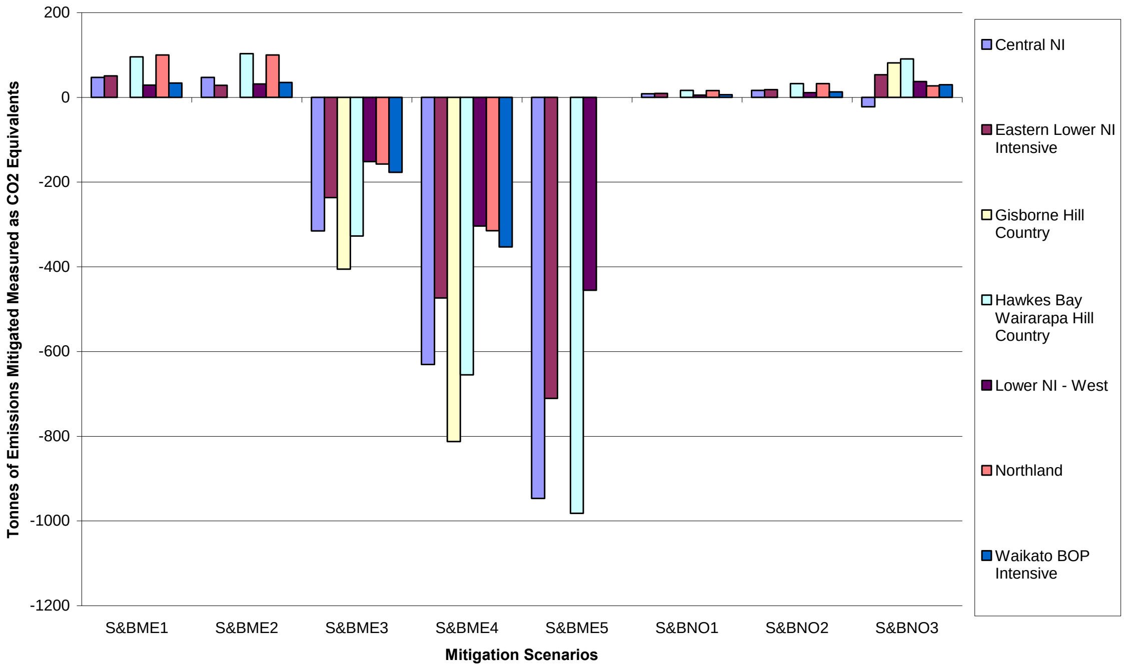
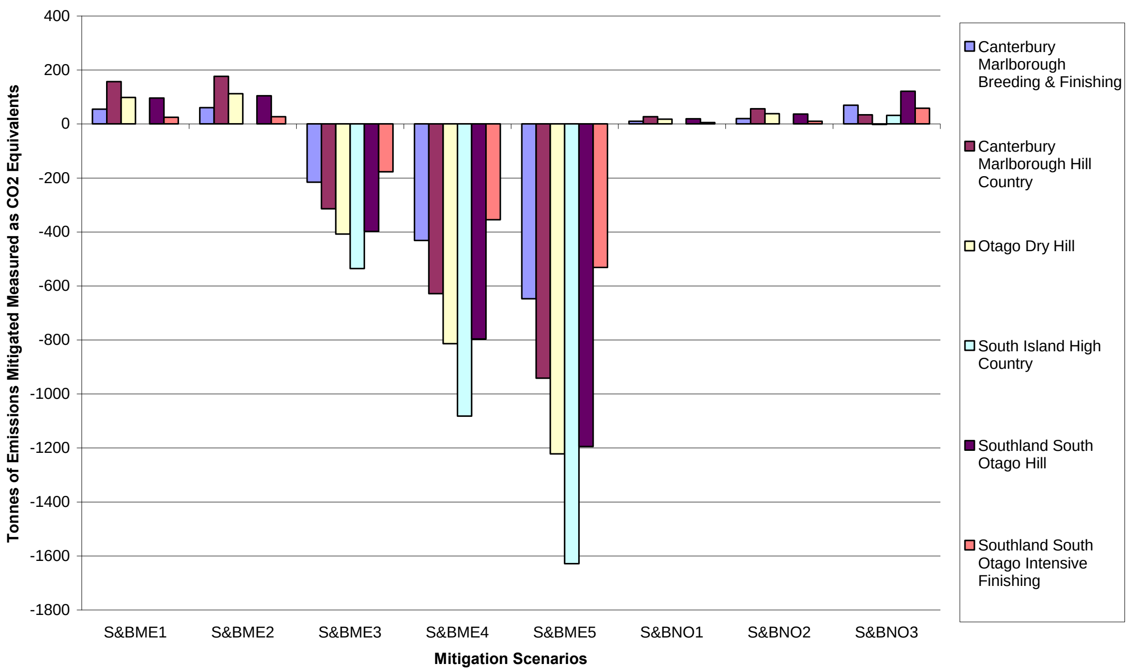


Figure 4.4: Mitigation of greenhouse gas emissions for each South Island sheep and beef representative farm (tons of CO2-e, 2006/07)



Figures 4.3 and 4.4 display the emission reductions of the North and South Island sheep and beef representative farms respectively. The overall level of reduction is

lower than the dairy sector, with no strategy mitigating more than 150 tons of CO_2 equivalents in the North Island. Hawkes Bay/ Wairarapa achieved the highest emission reductions in the North Island, equal to 103 tons of CO_2-e. This is due to the relative intensity and regional structure of this representative farm. Increased purchased feed (strategies S&BME3-5) increased production as well as emissions, with the increased percentage change in production higher than the increase in emissions.

There is greater mitigation of emissions for the South Island sheep and beef farming sector to reduce emissions, compared to the North Island. The largest reduction was in the Canterbury/Marlborough hill country farm, equal to 176 tons of CO_2 equivalents. This is due to the higher effective area compared to other representative farms. The two best strategies for the South Island sheep and beef representative farms were S&BME1 and S&BME2. These achieved the highest mitigation overall for the regions. Results as a proportion of base emissions are displayed below.

Figure 4.5: Mitigation of greenhouse gas emissions for each North Island sheep and beef representative farm, expressed as a percentage of base case emissions (2006/07)

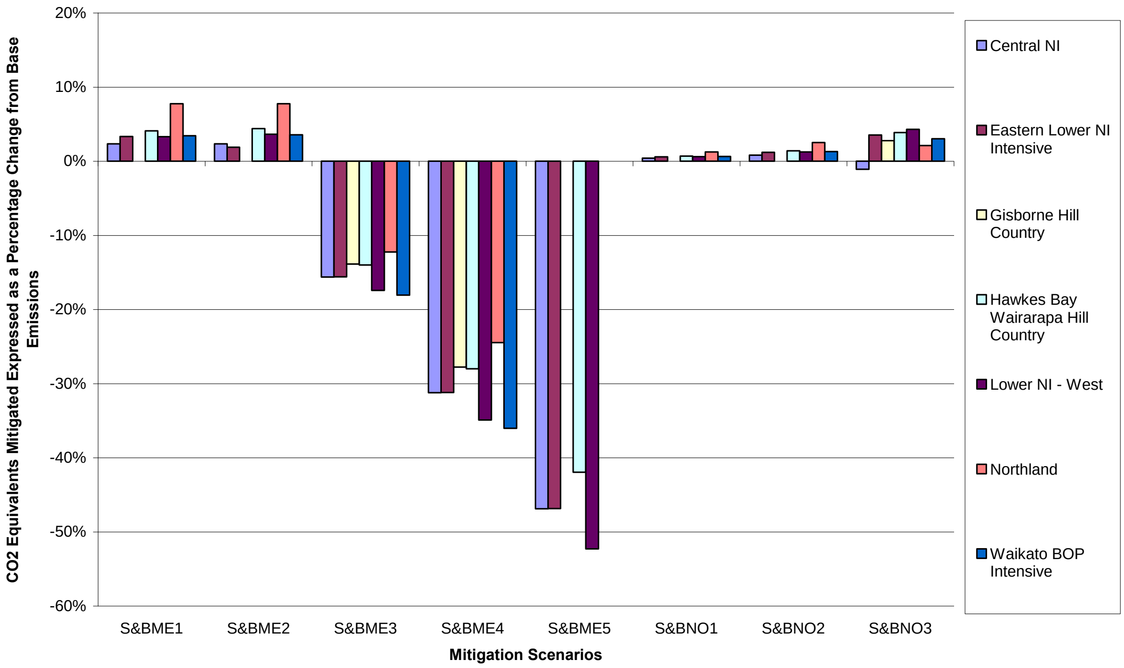
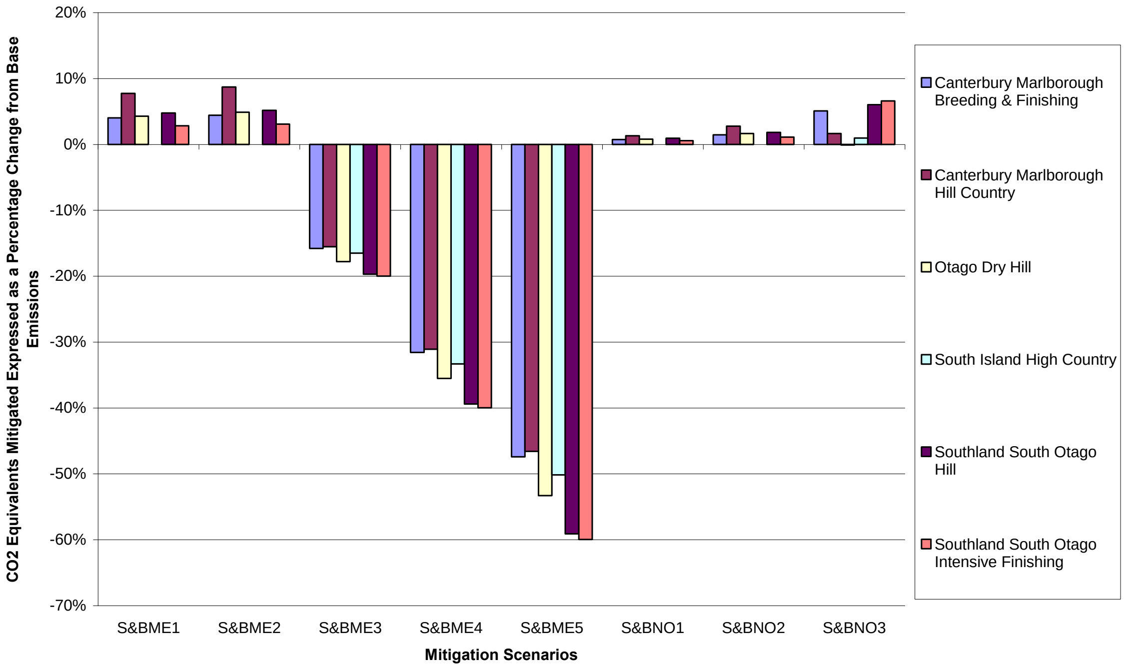


Figure 4.6: Mitigation of greenhouse gas emissions for each South Island sheep and beef representative farm, expressed as a percentage of base case emissions (2006/07)



Figures 4.5 and 4.6 show the percentage change in emission reductions for North and South Island sheep and beef representative farms respectively. The first graph shows that no North Island farm can achieve a 10 percent reduction in emissions through the analysed mitigation strategies, the largest mitigation being Northland with an 8 percent reduction. The two strategies with the greatest impact on North island farms are S&BME1-2. Therefore, North Island sheep and beef farmers must look at other mitigation options.

Similar to the North Island, no South Island representative farm under any analysed strategy can achieve a 10 percent reduction in emissions from the base case. Similar strategies are just as effective in the South Island compared to the North Island. Again South Island sheep and beef farmers require other options to meaningfully mitigate greenhouse gases.

4.1.3 Alternate representation/measures of emissions

Alternate measures of greenhouse gas mitigation, such as intensity, are important to consider for policymakers and farmers alike. To meet Kyoto objectives, New Zealand has to reduce emissions to 1990 levels. However, the national system (ETS) does not necessarily need to directly target 1990 emission levels to achieve Kyoto goals as these are two separate pieces of legislation. Therefore, New Zealand can implement an alternative target at the domestic level to meet international agreements. Intensity measures can be used to target industries or firms which are least productive in terms of emissions per unit of output. Such measures set environmental industry standards to meet and exceed. Changing the environmental measure for farmers to meet will alter industry behaviour and decision making processes as they respond to additional constraints imposed by policymakers.

4.1.4 Emissions per unit of output

An alternative target farmers can meet is emissions per unit of output. Through increasing animal yield, the emissions associated with maintenance are diluted. Maintenance emissions are the level of emissions when the animal is fed, such that it does not grow or produce any output. This measure is demonstrated below using dairy industry methane strategies.

Table 4.6: Emissions per unit of production, for dairy methane scenarios (Kg CO_2-e per Kg milk solids)

	Current Farm	**DME 1**	**DME 2**	**DME 3**	**DME 4**	**DME 5**	**DME 6**	**DME 7**	**DME 8**
Northland	13.07	13.16	13.03	12.79	8.90	12.91	12.32	11.39	7.22
Waikato/BOP	9.99	10.21	10.25	10.28	5.42	9.72	9.47	9.20	4.63
Taranaki	9.96	9.69	9.62	9.50	5.38	9.71	9.46	9.19	4.69
LNI	9.77	9.50	9.37	9.25	5.84	9.51	9.25	9.00	5.07
Canterbury	9.90	9.81	9.69	9.58	4.41	9.69	9.47	9.07	3.88
Southland	8.88	8.65	8.84	8.81	4.75	8.70	8.50	8.32	4.18

Table 4.6 displays the CO_2 equivalent emissions associated with one kilogram of milk solids. Canterbury achieves the lowest emission reduction under scenario DME8,

falling to 3.88 kg of CO_2-e emissions for one kilogram of milk solids. This is nearly twice as efficient as Northland, as Canterbury has a relative size advantage compared to all other regions. All other farming regions attain their lowest level of emissions per unit of output under DME8. Scenarios DME1-3 are designed to reduce emissions per unit of production. However, emissions per unit of production are not practically reduced compared to other scenarios, and in some cases emissions per unit of production increase from the base case. These three scenarios will not be pursued in the financial results because of the negligible effect on emissions per unit of output, and the increase in emissions.

4.1.5 OVERSEER Modelling Issue

There was an issue when running the model for dairy representative farms. For the DCD scenario, it was postulated from the literature, and OVERSEER, that adding DCD to pasture would improve production as it promotes pasture growth. However, dairy production did not change when DCD was applied to pasture and instead remained constant, although nitrous oxide emissions were reduced. This case contrasted with the sheep and beef situation where production increased. As this inconsistency was isolated to the dairy sector it did not affect comparisons between dairy farms for the DCD scenario, but it could affect the relative ranking of this scenario compared to other dairy scenarios.

4.2 Effects on Financial Position

Farmers are financially affected from changing current farming practices to reduce greenhouse gas emissions. Within the analysis, farming variables unaffected by the mitigation strategy are assumed to stay constant, as per the partial budgeting framework. This enables financial profit or loss to be explicitly calculated. Sensitivity analysis is used to determine the extent to which the current high price affects profitability and the results. Scenarios that increase emissions (DME1-3, and S&BME3-5) are not included within the financial analysis, as discussed previously. The first section examines the financial changes for the Waikato/BOP representative dairy farm.

4.2.1 Dairy

Table 4.7: Additional costs / forgone revenue, for the Waikato/BOP dairy representative farm (2007/08)

	Wintering/ Feed pad costs (p.a.)	**Maintenance costs (feed or winter pad)**	**DCD**	**Milk solids**	**Purchased feed**	**Total**
DME4	-$ 6,168	-$ 2,920			-$ 11,250	-$ 20,338
DNO1				-$ 27,328		-$ 27,328
DNO2				-$ 49,803		-$ 49,803
DNO3			-$ 16,274			-$ 16,274
DNO4					-$ 11,250	-$ 11,250
DNO5	-$ 6,168	-$ 2,920			-$ 11,250	-$ 20,338
DNO6	-$ 6,168	-$ 2,920	-$ 16,274		-$ 11,250	-$ 36,612

Table 4.8: Additional revenue / forgone costs, for the Waikato/BOP dairy representative farm (2007/08)

	Fertiliser	Smaller herd size	Total
DME4	$ 17,250		$ 17,250
DNO1	$ 8,625	$ 1,388	$ 10,013
DNO2	$ 17,250	$ 3,032	$ 20,282
DNO3			$ -
DNO4	$ 17,250		$ 17,250
DNO5	$ 17,250		$ 17,250
DNO6	$ 17,250		$ 17,250

Tables 4.7 and 4.8 display the financial cost changes of implementing dairy mitigation strategies for the Waikato/BOP representative farm. All figures are stated in dollars per year. The breakdown for other dairy representative farms can be found in the appendix. Through not adding nitrogen fertiliser to the farm, additional costs/forgone revenue are heavily affected when production falls. The high price received for production (milk solids) adversely affects these scenarios. Scenarios that contain feed or wintering pads also have high additional costs as the total capital cost of building them is large, creating a substantial annualised cost for the farmer. The cost to purchase additional feed such that production remains constant from the base case is $11,250 for the Waikato/BOP representative farm.

The magnitude of the additional revenue/forgone costs sometimes outweighs the magnitude of the additional costs/forgone revenue. In such situations, farmers can profit from implementing these scenarios. Scenario DNO4 has the largest gain in profit, by simply replacing nitrogen fertiliser with additional purchased feed to keep metabolisable energy constant. The calculated forgone costs associated with reducing nitrogen fertiliser use to zero are $17,250, with the cost of the additional maize feed at $11,250. Combining the two above tables provides a decision table (for all representative farms) to determine the most profitable (minimised loss) mitigation option.

Table 4.9: Profit changes from each mitigation strategy, for all dairy representative farms, per financial year (2007/08)

	DME4	DN01	DN02	DN03	DN04	DN05	DN06
Northland	-$4,344	-$7,083	-$9,620	-$17,064	$3,250	-$4,344	-$21,408
Waikato/BOP	-$3,088	-$17,315	-$29,521	-$16,274	$6,000	-$3,088	-$19,362
Taranaki	-$2,623	-$15,840	-$36,359	-$15,168	$5,625	-$2,623	-$17,791
LNI	-$5,172	-$15,072	-$30,019	-$20,540	$6,032	-$5,171	-$25,711
Canterbury	$14,524	-$60,272	-$125,905	-$32,074	$21,344	$118	-$31,956
Southland	$6,325	-$35,839	-$72,121	-$32,864	$11,225	-$4,025	-$36,889

Table 4.9 displays the change in profit from the mitigation strategies for all dairy representative farms. The table is derived from the summation of additional costs/forgone revenue and the additional revenue/forgone costs categories. Positive monetary values in table 4.15 are interpreted as additional profit. Due to the high price of milk solids scenarios DNO1 and DNO2, which reduce production through reduced fertiliser use, are not profitable in any dairy farming region within New Zealand. If the Canterbury representative farm did not apply any nitrogen fertiliser (DNO2) then profit will fall by over $125,000 per year. By extending the scenarios DNO1 and DNO2, by feeding maize silage such that production does not fall, farmers can increase profit while reducing nitrogen fertiliser use to zero (shown as DNO4). This is the most profitable scenario for farmers, and would be the preferred option for all representative farms. Because Canterbury is the largest representative farm, it has the largest increase in profit of $21,344 under DNO4. Canterbury"s larger effective area also means DCD application is more expensive compared to smaller farms (DNO3). There is a large difference in profit between the result of DNO5 and DNO6 whilst the marginal abatement of greenhouse gas emissions between the two scenarios is low. Effects on farm profitability are not the only factors the farmer needs to consider. The effect of each scenario on greenhouse gas mitigation affects whether the farmer should implement the strategy or purchase carbon credits on the open market. Dividing the above table by the tons of CO_2-e mitigated from each scenario, gives the cost (benefit) per ton of mitigation, displayed below.

Table 4.10: Dollars per ton of CO2-e mitigated, for each representative dairy farm

	DME4	DN01	DN02	DN03	DN04	DN05	DN06
Northland	-$16	-$182	-$123	-$386	$13	-$18	-$79
Waikato/BOP	-$7	-$241	-$205	-$401	$15	-$8	-$46
Taranaki	-$7	-$226	-$260	-$363	$16	-$7	-$41
LNI	-$12	-$207	-$207	-$249	$57	-$11	-$54
Canterbury	$10	-$230	-$240	-$150	$27	$0	-$21
Southland	$8	-$268	-$269	-$224	$15	-$5	-$40

Table 4.10 combines table 4.9 with CO_2-e mitigation results. There are two choices for the farmer to meet emissions targets; to mitigate on farm greenhouse gas emissions, or purchase carbon credits. Table 4.10 creates an identical unit to purchasing carbon credits. This table has a similar sign interpretation to table 4.9 where negative values imply that farm profits fall. For example, the Northland representative dairy farmer can mitigate greenhouse gas emissions at $16 per tonne of CO_2 equivalents under DME4. If the farmer can purchase carbon credits for $20, then the farmer would be better off altering the current farming practice and implementing DME4. However, if the carbon price was $10, then the farmer would be better off purchasing carbon credits on the open market and keeping to the base case farming situation. Within the same scenario, the representative Southland dairy farm profits by $8 for every ton of CO_2-e emissions mitigated from implementing the same strategy. DNO3 is the worst strategy to implement as it gives the highest price to mitigate greenhouse gas emissions, as carbon credit prices would have to reach over $363 for the representative Taranaki dairy farmer to implement DNO3. Any carbon credit price less than $363 would leave the farmer better off through purchasing carbon credits, and continuing emit the same amount of emissions under the base case. The results presented here are influenced by the price assumptions used within the study. Sensitivity analysis is performed to test the relative rankings of strategies.

4.2.1.1 Sensitivity analysis

The financial results are dependent on the price assumptions used within the study. Therefore, two price assumptions are tested; the price of milk solids, and maize silage. The milk solids price used (2007/08) is high compared to historical payouts. Therefore, a price of $4 per kg is used to test to what extent the results are altered.

Some scenarios are not affected as production is held constant, while others are more exposed to changes in the price of milk solids. Purchased maize silage is another major input that is altered through some mitigation strategies. Hence, a price increase of maize silage feed from 15 to 20 cents per kg of dry matter is also investigated. This scenario is tested separately from reducing the price of milk solids.

Table 4.11: Alternate scenario, dollars per ton of CO_2-e mitigated for each dairy representative farm, when milk solids are $4 per kg (2007/08)

	DME4	DN01	DN02	DN03	DN04	DN05	DN06
Northland	-$16	-$35	-$2	-$386	$13	-$18	-$79
Waikato/BOP	-$7	-$65	-$45	-$401	$15	-$8	-$46
Taranaki	-$7	-$58	-$77	-$363	$16	-$7	-$41
LNI	-$12	-$47	-$47	-$249	$57	-$11	-$54
Canterbury	$10	-$60	-$65	-$150	$9	$0	-$21
Southland	$8	-$80	-$81	-$224	$15	-$5	-$40

Table 4.11 displays the change in profit to mitigate one ton of CO_2-e emissions, a measure analogous to purchasing carbon credits, under the assumption that the price for milk solids has fallen to $4/kg. Scenarios DNO1 and DNO2 are affected by this change. Interestingly, there are no sign changes for all representative farms. Under DNO2, the LNI farmer will implement this strategy when the carbon credit price is above $47, compared to the previous threshold of $207. This shows that the cost of reducing nitrogen fertiliser use by the farmer is sensitive to the price assumption. The farmer will still prefer DNO4 when the milk solids price is reduced. Maize silage is another important input for mitigation strategies. This sensitivity analysis is performed by increasing the price of maize silage from 15 cents to 20 cents per kg of dry matter (DM) (milk solids price is the same as the base case).

Table 4.12: Alternate scenario, dollars per ton of CO_2-e mitigated for each dairy representative farm, when maize silage is 20 cents/kg DM (milk solids price is the same as the base case) (2007/08)

	DME4	DN01	DN02	DN03	DN04	DN05	DN06
Northland	-$21	-$182	-$123	-$386	$5	-$27	-$87
Waikato/BOP	-$11	-$241	-$205	-$401	$6	-$17	-$55
Taranaki	-$13	-$226	-$260	-$363	$6	-$17	-$50
LNI	-$18	-$207	-$207	-$249	$20	-$20	-$63
Canterbury	$0	-$230	-$240	-$150	$10	-$10	-$30
Southland	-$1	-$268	-$269	-$224	$5	-$13	-$48

Scenarios DME4, and DNO4-6 inclusive are negatively affected by the increase in maize silage prices. The five cent price increase changes the sign for one strategy and reduces another to zero. DME4 for Southland changes sign and falls from $8 to -$1. Canterbury fell from $10 to $0 per tonne of CO_2-e mitigated; therefore with the price increase the farmer is indifferent to implementing the strategy with a carbon credit price of zero. The Canterbury representative farm under DNO4 for was largely affected, as the larger herd requires comparatively greater amounts of purchased feed. The increase in maize silage price alters the price of mitigation by approximately $10 per tonne of CO_2-e emissions for scenarios DNO4-6.

4.2.2 Sheep and beef results

As discussed previously, the sheep and beef mitigation results are not as large compared to the dairy results. Intensity differences between the two farming systems can account for much of the difference, where the sheep and beef sector is characterised by low intensity over a large farming area. This intensity difference is likely to also be accountable for the less profitable financial results. Sheep and beef financial results for the Waikato/BOP representative farm are presented below.

Table 4.13: Additional costs / forgone revenue, for the Waikato/BOP sheep and beef representative farm (2006/07)

	Prod. change	**Larger herd**	**DCD**	**Purchased feed**	**Wintering pad**	**Maintaining winter pad**	**Total**
S&BNO1	-$694						-$ 694
S&BNO2	-$1,387						-$ 1,387
S&BNO3		-$197	-$39,500				-$ 39,697
S&BME1				-$1,050			-$ 1,050
S&BME2				-$1,050	-$ 29,847	-$14,130	-$ 45,027

Table 4.14: Additional revenue / forgone costs, for the Waikato/BOP sheep and beef representative farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$25	$750		$775
S&BNO2	$51	$1,500		$1,551
S&BNO3			$5,318	$5,318
S&BME1		$1,500		$1,500
S&BME2		$1,500		$1,500

Results for other sheep and beef representative farms are presented in the appendix. The two greatest costs for all the strategies involve the application of DCD and constructing a wintering pad. The large effective area of each sheep and beef farm (relative to the effective area of the representative dairy farms) creates a large cost to apply DCD biannually. But in contrast, the greatest income effect is attained from an increase in production under scenario S&BNO3. Further, greater cattle numbers increase the construction costs of the wintering pad along with yearly maintenance costs. Changes in revenue are calculated by taking the percentage increase in production from the mitigation simulations, then using that percentage to increase or decrease revenue from base revenue (as outlined in the methodology). This implicitly assumes that stock prices have not changed since 2006/07. The overall impact for all sheep and beef representative farms is displayed below.

Table 4.15: Profit changes from each mitigation strategy, for all sheep and beef representative farms (per financial year) (2006/07)

	S&BNO1	S&BNO2	S&BNO3	S&BME1	S&BME2
Canterbury Marlborough Breeding & Finishing	$445	$890	-$52,796	$875	-$24,273
Canterbury Marlborough Hill Country	$1,845	$3,691	-$203,477	$2,375	-$58,377
Central NI	$428	$855	-$91,170	$650	-$61,659
Eastern Lower NI Intensive	$31	$406	-$47,607	$625	-$49,795
Gisborne Hill Country			-$129,718		
Hawkes Bay Wairarapa Hill Country	$906	$1,812	-$90,340	$1,325	-$49,561
Lower NI - West	$165	$483	-$29,334	$350	-$25,731
Northland	$748	$1,694	-$48,224	$1,325	-$72,344
Otago Dry Hill	$687	$1,749	-$278,867	$1,525	-$25,552
South Island High Country			-$1,660,264		
Southland South Otago Hill	$813	$1,627	-$102,022	$1,500	-$23,928
Southland South Otago Intensive Finishing	$255	$325	-$26,028	$500	-$3,702
Waikato BOP Intensive	$82	$164	-$34,378	$450	-$43,527

Table 4.15 shows the farm profit changes for sheep and beef representative farms within New Zealand. Sheep and beef farmers can profit from reducing nitrogen fertiliser use (scenarios S&BNO1 and S&BNO2), although the profit increase is generally less than $2,000, per farm, per year. Sheep and beef farms typically use little nitrogen fertiliser, therefore the magnitude of the change in profit associated with S&BNO1-2 and S&BME1 is relatively minor. Profits fall dramatically under S&BNO3 (use of DCD). As sheep and beef farms are much larger than their dairy counterparts in terms of effective area, DCD application is aimed primarily at dairy farmers as the cost is prohibitively high. The South Island High Country representative farm faces a yearly financial liability of $1.6 million to apply DCD. Methane mitigation strategies provide few profitable options for farmers to reduce emissions. The above table can be combined with mitigation results to calculate profit per tonne of CO_2-e mitigated, presented below.

Table 4.16: Dollars per ton of CO_2-e mitigated, for each sheep and beef representative farm (2006/07)

	S&BNO1	S&BNO2	S&BNO3	S&BME1	S&BME2
Canterbury Marlborough Breeding & Finishing	$45	$45	-$763	$16	-$401
Canterbury Marlborough Hill Country	$70	$66	-$6,069	$15	-$332
Central NI	$52	$52		$14	-$1,312
Eastern Lower NI Intensive	$ 3	$23	-$891	$12	-$1,750
Gisborne Hill Country			-$1,596		
Hawkes Bay Wairarapa Hill Country	$56	$56	-$998	$14	-$481
Lower NI - West	$30	$45	-$783	$12	-$814
Northland	$47	$52	-$1,786	$13	-$725
Otago Dry Hill	$38	$46		$16	-$228
South Island High Country			-$52,667		
Southland South Otago Hill	$43	$44	-$840	$16	-$230
Southland South Otago Intensive Finishing	$53	$34	-$446	$20	-$136
Waikato BOP Intensive	$13	$13	-$1,156	$13	-$1,244

Table 4.16 displays a measure analogous to purchasing carbon credits, the cost or benefit to mitigate an additional tonne of greenhouse gas emissions. All regions can profit from reducing nitrogen fertiliser use by half, or to zero (shown by positive values in the table). Gisborne and South Island high country representative farms apply zero nitrogen fertiliser in the base case. However, as shown in the previous table (table 4.15) the change in profit from reducing fertiliser use is small. When production is kept constant compared to the base case after reducing nitrogen fertiliser use to zero, the farmer can increase profit by purchasing maize silage (S&BME1). The cost of adding a wintering pad is prohibitively expensive, and would be ruled out with low carbon credit prices. Despite DCD application adding a large cost to sheep and beef farmers, it gives little in terms of mitigating greenhouse gas emissions. This is shown under S&BNO3, where the carbon credit price would have to be over $446 per tonne of CO_2-e emissions before any sheep and beef farmer would apply DCD to their farm. DNO1-2 provides the highest profit per tonne of CO_2-e mitigated. Other mitigation strategies outside the scope of this study need to be investigated for the sheep and beef industry to meaningfully reduce greenhouse gas emissions.

4.3 Regional and National Results

The previous physical and financial analysis is performed at the farm level. From this micro level the results can be scaled up to the macro level to gain additional understanding about national farm greenhouse gas emissions[9]. The analysis assumes that each sector within each region is liable to meet emission targets. National costs and benefits can be calculated to assess the possible national burden on the two sectors. This section will be split into two parts. The first part deals with the physical and financial results of the dairy, and sheep and beef regions, while the second part examines each sector meeting Kyoto emission targets. Dairy financial and physical results are presented below, followed by the sheep and beef sector.

Table 4.17: Selected regional dairy farm summary statistics (2007/08)

	Dairy effective area (ha)[10]	**Calculated number of farms**	**Base Case emissions per farm (tons CO_2-e)**	**Total regional emissions (tons/year)**	**Percentage of total dairy emissions**
Northland	46,184	427	847	361,549	2%
Waikato/BOP	624,941	6,067	958	5,812,829	36%
Taranaki	101,742	1,059	876	927,277	6%
LNI	372,938	2,868	1,118	3,205,305	20%
Canterbury	295,315	1,454	2,661	3,868,393	24%
Southland	249,518	1,199	1,741	2,087,660	13%
Total	**1,690,636**	**13,074**		**16,263,015**	

Table 4.17 displays selected summary statistics at the regional level for the dairy sector in New Zealand. Using the regional dairy effective area and the representative farm effective area, it is possible to calculate the average number of representative farms for each region. From here, emissions for the representative farm are multiplied by the number of farms within that region to give total regional emissions. The biggest emitting region is Waikato/BOP with 5.8 million tons of CO_2-e, or 36 percent of total dairy emissions. The other two high emitting regions are the LNI and

9 Results from the predicted total national emissions for agriculture are marginally lower than the estimation from the national inventory, with a difference of 0.87Mt (approximately 2 percent difference).
10 Land data drawn from Rae (2008).

Canterbury, where the latter has less than half the regional effective area of Waikato. This regional result contrasts with the representative farm effective area, where the Canterbury representative farm is much larger compared to any other representative farm. Regionally, Canterbury has approximately half the number of farms compared to the LNI. Waikato, LNI, and Canterbury combined account for 80 percent of total dairy emissions. Presented below are the mitigation results for each dairy region.

Table 4.18: Total mitigation for each dairy region 2007/08 (CO_2-e, 000"s of tons)

	Base Case Emissions	**DME4**	**DN01**	**DN02**	**DN03**	**DN04**	**DN05**	**DN06**
Northland	362	115	17	34	19	105	102	115
Waikato/BOP	5813	2657	436	873	246	2406	2471	2536
Taranaki	927	427	74	148	44	381	382	454
LNI	3205	1289	208	416	236	302	1322	1354
Canterbury	3868	2146	381	763	311	1149	1973	2196
Southland	2088	971	161	322	176	915	1061	1099
Total	**16263**	**7606**	**1277**	**2556**	**1032**	**5258**	**7311**	**7754**

Table 4.18 shows the mitigation achieved by each dairy strategy aggregated to the regional level, and presented in thousands of tons (CO_2-e). This shows which region attains the largest mitigation of emissions given that all farms in the region implement the mitigation scenario. The column „Base Case Emissions" gives the calculated initial regional emissions. Waikato/BOP again has the largest mitigation compared to other regions due to the prevalence of dairy farming within the region. Scenario DNO6 has the highest mitigation for all regions combined. There is a stark contrast between the mitigation from scenario DNO2 between Northland and Waikato/BOP. This is due to the effectiveness of the strategy, in the Waikato/BOP region combined with the prevalence of dairy farming within the region. The Northland region mitigates 34 thousand tons of CO_2-e emissions, whilst the Waikato/BOP mitigates 873 thousand tons. The total regional profitability changes of mitigation are represented below.

Table 4.19: Dairy total regional change in profit from implementing each strategy (2007/08, $m)

	DME4	DN01	DN02	DN03	DN04	DN05	DN06
Northland	-$1.85	-$3.02	-$4.11	-$7.29	$1.39	-$1.85	-$9.14
Waikato/BOP	-$18.73	-$105.05	-$179.10	-$98.73	$36.40	-$18.73	-$117.47
Taranaki	-$2.78	-$16.77	-$38.50	-$16.06	$5.96	-$2.78	-$18.84
LNI	-$14.83	-$43.23	-$86.09	-$58.91	$17.30	-$14.83	-$73.74
Canterbury	$21.12	-$87.64	-$183.07	-$46.64	$31.03	$0.17	-$46.46
Southland	$7.58	-$42.97	-$86.47	-$39.40	$13.46	-$4.83	-$44.23
National Δ profit	**-$9.50**	**-$298.68**	**-$577.35**	**-$267.03**	**$105.54**	**-$42.85**	**-$309.88**
National Emissions[11]	**8657**	**14986**	**13707**	**15231**	**11920**	**11335**	**11529**

Table 4.19 represents the regional and national change in profit from implementing greenhouse gas mitigation strategies for the New Zealand dairy sector. Within the above table, positive values indicate a rise in profit. Both Canterbury and Southland profit from scenario DME4 as they already have constructed a feed pad (given the assumption that the representative farm has already installed a feed pad), and therefore no construction costs are incurred under partial budgeting. All dairy farming regions can profit from reducing fertiliser use to zero, then purchase feed to keep production constant. This scenario (DNO4) has the highest overall profit increase. Similar analysis for the sheep and beef sector is displayed below.

[11] Measured as 000‟s tons of CO_2-e

Table 4.20: Selected regional sheep and beef farm summary statistics (2006/07)

	Number of farms in each region	Sheep and Beef effective area (ha)	Base Case emissions per farm (tons CO2-e)	Total regional emissions (tons CO_2-e/year)	Percentage of total S&B emissions
Canterbury/Marlborough Breeding & Finishing	1,650	623,700	1366	2,253,428	11%
Canterbury/Marlborough Hill Country	425	593,725	2021	859,120	4%
Central North Island	2,220	1,409,700	2019	4,482,846	22%
Eastern Lower North Island Intensive	805	279,335	1517	1,221,532	6%
Gisborne Hill Country	605	496,705	2925	1,769,760	9%
Hawkes Bay/Wairarapa Hill Country	1,165	726,960	2341	2,726,827	13%
Lower NI - West	420	87,360	871	365,689	2%
Northland	980	307,720	1287	1,261,037	6%
Otago Dry Hill	400	800,000	2292	916,800	4%
South Island High Country (merino)	220	2,311,760	3247	714,334	3%
Southland/South Otago Hill	720	520,560	2022	1,455,486	7%
Southland/South Otago Intensive Finishing	1,700	329,800	887	1,507,186	7%
Waikato/BOP Intensive	1,055	263,750	980	1,034,164	5%
Total	**12,365**	**8,751,075**		**20,568,208**	

The above table summarises selected physical characteristics of each sheep and beef farming region. The number of farms each representative farm symbolises is used to calculate regional emissions. Approximately 8.75 million hectares are dedicated to sheep and beef farming nationally according to the above calculation, which compares to 8.98 million hectares nationally as calculated by A. Rae (personal communication, 7 September, 2008). The major emitting regions are Central North Island, Canterbury/Marlborough breeding and finishing, and Hawkes Bay/Wairarapa hill country, accounting for a combined total of 46 percent sheep and beef emissions. Even though Southland/South Otago finishing region has the second highest number of represented farms, due to the small area of the representative farm the region only accounts for 7 percent of sheep and beef emissions. In total, sheep and beef farming emits a total of 20.57 Mt, which is larger than total emissions associated with dairy farming. Regional results from the mitigation scenarios are presented below.

Table 4.21: Regional mitigation for sheep and beef farms (000‟s tons CO_2-e) (2006/07)

	Base Case	**S&BNO1**	**S&BNO2**	**S&BNO3**	**S&BME1**	**S&BME2**
Canterbury Marlborough Breeding & Finishing	2253	16	32	114	90	100
Canterbury Marlborough Hill Country	859	11	24	14	66	75
Central NI	4483	18	37	-49	104	104
Eastern Lower NI Intensive	1222	7	15	43	41	23
Gisborne Hill Country	1770	0	0	49	0	0
Hawkes Bay Wairarapa Hill Country	2727	19	38	105	111	120
Lower NI - West	366	2	5	16	12	13
Northland	1261	16	32	26	98	98
Otago Dry Hill	917	7	15	-1	39	45
South Island High Country	714	0	0	7	0	0
Southland South Otago Hill	1455	14	27	87	69	75
Southland South Otago Intensive Finishing	1507	8	16	99	43	46
Waikato BOP Intensive	1034	7	13	31	36	37
Total	**20568**	**126**	**253**	**543**	**710**	**736**

Taking the sheep and beef national results, the best strategy if implemented throughout the country, can reduce emissions by 736 thousand tons. This compares to the 20,568 thousand tons emitted as the base case. Expressed as a percentage, the total mitigation from the best strategy is 3.6 percent. Sheep and beef farmers will need to look to other mitigation technologies outside the scope of this study to reduce greenhouse gas emissions. The total regional change in revenue is displayed below.

Table 4.22: Sheep and beef total regional profit change from implementing each mitigation strategy (2006/07, $m)

	S&BNO1	S&BNO2	S&BNO3	S&BME1	S&BME2
Canterbury Marlborough Breeding & Finishing	0.73	1.47	-87.11	0.62	-40.05
Canterbury Marlborough Hill Country	0.78	1.57	-86.48	0.37	-24.81
Central NI	0.95	1.9	-202.4	0.44	-136.88
Eastern Lower NI Intensive	0.03	0.33	-38.32	0.1	-40.08
Gisborne Hill Country	0	0	-78.48	0	-64.57
Hawkes Bay Wairarapa Hill Country	1.06	2.11	-105.25	0.55	-57.74
Lower NI - West	0.07	0.2	-12.32	0.02	-10.81
Northland	0.73	1.66	-47.26	0.47	-70.9
Otago Dry Hill	0.27	0.7	-111.55	0.23	-10.22
South Island High Country	0	0	-365.26	0	-9.59
Southland South Otago Hill	0.59	1.17	-73.46	0.36	-17.23
Southland South Otago Intensive Finishing	0.43	0.55	-44.25	0.43	-6.29
Waikato BOP Intensive	0.09	0.17	-36.27	0.11	-45.92
National Δ Profit	**5.73**	**11.83**	**-1288.4**	**3.70**	**-535.09**
National emissions[12]	**20443**	**20315**	**20025**	**19858**	**19832**

Table 4.22 represents the regional and national profit change from implementing mitigation strategies for the New Zealand sheep and beef sector. Despite the low level of mitigation of all the above strategies for sheep and beef farming, reducing nitrogen fertiliser use (S&BNO1 and S&BNO2) will increase profit for sheep and beef farmers by $5.73 and $11.83 million respectively. Gisborne and the South Island high country representative farms both already use no nitrogen fertiliser. This is the only national management scenario that farmers can profit from, with all others imposing losses on the industry. However, the strategy with the largest cost is S&BNO3 of over $1.2 billion to mitigate a small percentage of greenhouse gas emissions. Another large cost for the sector is S&BME2 with a national loss in profit of $535 million. The next section examines a scenario where each sector is required to meet Kyoto emission targets.

4.3.1 Scenario: Meeting Kyoto targets

This section examines the cost to meet environmental policies for dairy, and sheep and beef farming in New Zealand. The domestic greenhouse gas policy (ETS) is yet to

[12] Measured as 000‟s tons of CO_2-e

be finalised, but as it presently stands agriculture is due to join the scheme in 2013 with the point of obligation at the processor level, for the two industries. New Zealand is also a signatory to the Kyoto protocol, an international agreement with the aim of reducing greenhouse gas emissions. Kyoto and the ETS can be viewed as separate pieces of legislation. The scenario examined to meet emission reductions is based on the Kyoto agreement, a reduction in emissions to 1990 levels. Using the 2006 national inventory of agricultural emissions, agricultural emissions have increased 15.9 percent between 1990 and 2006 and are assumed to be the emissions target within this scenario. Total agricultural emissions are used as the national inventory does not split emissions based on dairy or sheep and beef sufficiently. It is assumed that each region (of each sector) will individually meet its own Kyoto target such that the national emissions target is met. In reality, the burden will be spread differently throughout the country. If the sector (or region) is unable to meet the emissions targets through mitigation strategies, carbon credits will need to be purchased to meet this difference. Different carbon prices will result in different thresholds for mitigation strategies, as some scenarios become financially viable with high carbon credit prices or financially unviable with lower carbon credit prices.

There are a range of scenarios that have been investigated above for farmers to implement to reduce emissions. The scenario that gives a satisfactory result for the trade-off between emissions reduction and financial burden, will be used in the scenario to meet the Kyoto target. Scenario DNO4, reducing nitrogen fertiliser use to zero and importing maize silage to keep production the same from base case, financially benefits farmers and meaningfully reduces emissions. However, the level of greenhouse gas mitigation for the LNI representative farm is low under DNO4, hence DME4 is used instead. A summary table is provided below outlining which scenarios are implemented in each region, starting with the dairy sector.

Table 4.23: Dairy strategies implemented to meet the Kyoto target (000"s of CO_2-e tons)

	Mitigation strategy	Effectiveness of strategy	Emissions to reduce to 1990 level	Percent of adoption required
Northland	DNO4	105	58	55%
Waikato/BOP	DNO4	2406	924	38%
Taranaki	DNO4	381	147	39%
LNI	DME4	1289	510	40%
Canterbury	DNO4	1149	615	54%
Southland	DNO4	915	332	36%
Total		**6245**	**2586**	**41%**

Table 4.23 shows the effectiveness of the best choice strategy at the regional level and the amount of mitigation required to meet the Kyoto target. The ratio of these two numbers gives the percentage of farms within the region that are required to adopt the mitigation strategy to meet the Kyoto target. For example, the Northland region needs to mitigate 58,000 tons of CO_2 equivalents to meet the Kyoto target. A 100 percent adoption strategy of DNO4 will mitigate 105,000 tons of CO_2-e, therefore only 55 percent of dairy farmers within the region will need to implement DNO4 to meet the target. The lowest percentage of adoption required is in the Southland region with only 36 percent of dairy farmers needing to implement DNO4 to meet the Kyoto target.

Table 4.24: Dairy profit change of adoption, and counterfactual carbon credit cost for the status quo ($m)

	Profit change from adoption	Carbon price per ton of CO_2-e		
		$20	**$50**	**$100**
Northland	$0.77	$1.15	$2.88	$5.76
Waikato	$13.98	$18.49	$46.21	$92.43
Taranaki	$2.32	$2.95	$7.37	$14.74
LNI	-$5.85	$10.19	$25.48	$50.96
Canterbury	$5.41	$12.30	$30.75	$61.50
Southland	$4.85	$6.64	$16.60	$33.20
Total	**$21.48**	**$51.72**	**$129.29**	**$258.58**

Table 4.24 displays the cost to the dairy sector in meeting its Kyoto objective which is assumed to reduce 2006 agricultural CO_2 equivalent emissions to 1990 levels, a 15.9 percent reduction. Nationally, the dairy sector can meet its Kyoto target and nationally profit by $21.48 million. In contrast, if the dairy sector did nothing it would be liable for $51.72 million worth of carbon credit purchases at a carbon credit price of $20.

Waikato/BOP and Canterbury are the two regions which profit the most from mitigating emissions. LNI loses profit by implementing strategy DME4. Given the assumptions, only the LNI farmers would purchase carbon credits on the open market, as this is a cheaper option compared to mitigation. Similar analysis of the sheep and beef sector is displayed below.

Table 4.25: Sheep and beef strategies implemented to meet the Kyoto target (thousands of CO_2-e tons)

	Mitigation strategy	**Effectiveness of strategy**	**Emissions to reduce**	**Percent of adoption required**
Canterbury Marlborough Breeding & Finishing	S&BME1	90	358	398%
Canterbury Marlborough Hill Country	S&BME1	66	137	208%
Central NI	S&BME1	104	713	686%
Eastern Lower NI Intensive	S&BME1	41	194	473%
Gisborne Hill Country			281	
Hawkes Bay Wairarapa Hill Country	S&BME1	111	434	391%
Lower NI - West	S&BME1	12	58	483%
Northland	S&BME1	98	200	204%
Otago Dry Hill	S&BME1	39	146	374%
South Island High Country			114	
Southland South Otago Hill	S&BME1	69	231	335%
Southland South Otago Intensive Finishing	S&BME1	43	240	558%
Waikato BOP Intensive	S&BME1	36	164	456%
Total		**709**	**3270**	**461%**

Table 4.25 shows the effect from scenario S&BME1, which consists of applying no nitrogen fertiliser whilst maintaining production from the base case by purchasing maize silage. This strategy gives a high level of mitigation for the associated cost (see table 4.16). The table shows that no region can mitigate the required amount of emissions to meet the Kyoto target, as 100 percent of farm level adoption is the physical limit. For the sector as a whole, it can mitigate 21.7 percent of emissions towards the required Kyoto target, therefore the remainder of the mitigation must be purchased through carbon credits. The financial implications of implementing the scenario are examined below.

Table 4.26: Sheep and beef profit change of adoption, and additional carbon credit cost to meet Kyoto ($m)

	Profit change from adoption	Carbon price per ton of CO_2-e $20	$50	$100
Canterbury Marlborough Breeding & Finishing	$0.62	$5.36	$13.41	$26.82
Canterbury Marlborough Hill Country	$0.37	$1.41	$3.53	$7.06
Central NI	$0.44	$12.18	$30.44	$60.88
Eastern Lower NI Intensive	$0.10	$3.07	$7.66	$15.33
Gisborne Hill Country		$5.63	$14.07	$28.14
Hawkes Bay Wairarapa Hill Country	$0.55	$6.45	$16.13	$32.26
Lower NI - West	$0.02	$0.92	$2.31	$4.62
Northland	$0.47	$2.05	$5.12	$10.25
Otago Dry Hill	$0.23	$2.14	$5.34	$10.68
South Island High Country		$2.27	$5.68	$11.35
Southland South Otago Hill	$0.36	$3.25	$8.12	$16.23
Southland South Otago Intensive Finishing	$0.43	$3.93	$9.83	$19.66
Waikato BOP Intensive	$0.11	$2.57	$6.42	$12.84
Total	**$3.70**	**$51.23**	**$128.07**	**$256.13**

Table 4.26 is similar to table 4.24, except the last three columns are an additional cost to 100 percent adoption of S&BME1. The corresponding dairy table is based on no adoption. Therefore, the last three columns of table 4.26 can be interpreted as an additional liability to implementing S&BME1. If the carbon credit price is $100 per tonne of CO_2 equivalents then the sector will be liable for an additional $256 million, but will profit by $3.7 million from implementing the mitigation strategies on all sheep and beef farms. These results confirm that the sheep and beef industry is required to look at options outside the scope of this study to meet Kyoto target, or it will require purchases from the international carbon credit market to offset current emissions.

5 Summary and Conclusions

The scope of greenhouse gas emissions literature and research is expansive. As it is such a large body of work, the focus of this research has been narrowed to scientifically proven management strategies that mitigate greenhouse gas emissions for agriculture. New Zealand is a relatively small nation with a small population. Even so, agriculture is the backbone of the New Zealand economy with over 13,000 dairy and 12,000 sheep and beef farms within the country. This size and reliance on agriculture means that emissions from the agricultural sector account for around 50 percent of national emissions. Compared to other nations, agriculture‟s share of national emissions is high. In 2013, agriculture is due to be liable for emissions under the ETS, giving policymakers time to finalise the details of the scheme.

There is a lack of quantitative New Zealand studies that examine how agriculture can adapt farming practices, in response to the ETS. This study attempts to quantify the financial and environmental effects from specific mitigation strategies that farmers can implement. The results help inform farmers of available management strategies and their effects at the farm level. Furthermore, results for individual farms can be easily replicated, as OVERSEER is freely available to the general public. A summary of the study combined with improvements and future work are outlined first, followed by conclusions.

5.1 Summary

Because there is no accepted methodology within the literature on quantifying how agriculture can adapt farming practices in response to emission reductions, partial budgeting is used. Partial budgeting is a planning and decision-making framework used to compare the costs and benefits of alternatives faced by a farm business. It focuses on the changes in income and expenses, along with physical characteristics, that would result from implementing a specific alternative. Thus, all aspects of farm profits that are unchanged by the decision can be safely ignored. This methodology has been used extensively within the farm literature.

To represent the New Zealand agricultural sector, dairy, and sheep and beef sectors are taken. These two sectors account for the majority of output and greenhouse gas emissions within New Zealand. Differences between the farming characteristics of each geographical region are captured by representative farms, where there are 6 dairy and 13 sheep and beef representative farms. The data for each representative farms is drawn from 50-60 real farms, with professional adjustments to reflect a real farm rather than simply an average of sampled farms. Values for each representative farm were then put into OVERSEER, to quantify the change in both the emissions profile and physical characteristics from mitigation strategies. The data was provided by Journeaux (personal communication, 21 May, 2008).

There are a wide range of mitigation options available to farmers for reducing greenhouse gas emissions. One recently proven scientific strategy to reduce emissions that is commercially available is the application of DCD (Di & Cameron, 2002, 2003, 2006). In addition, examined mitigation strategies involve; reducing nitrogen fertiliser usage, purchasing additional feed supplements (maize silage), application of DCD, productivity gains, and the construction of a wintering or feed pad. There are a plethora of mitigation strategies that have been tested by scientists; however the results for many of these studies are far from conclusive. Strategies that are scientifically unproven or not commercially available have been omitted from the study. Further testing is required to give farmers more options to mitigate emissions.

Mitigation strategies will not only reduce greenhouse gas emissions, but also impact on other environmental variables. For example, better nitrogen management will reduce direct N_2O emissions, and result in less nitrate leaching and emissions associated with leaching losses. Nitrous oxide mitigation strategies work primarily through more effective utilisation, and reduction, of nitrogen within the farming system. In addition, the less time animals spend on pasture the less excrement is deposited onto the pasture. This reduces nitrous oxide emissions as excrement is high in nitrogen content, and is lost to the air or soil before the plant can absorb the nitrogen. Therefore, abatement technologies that increase the efficiency of the soil-plant system are also likely to increase pasture growth. Methane mitigation strategies primarily work through animals eating a higher quality feed, that is easier to digest compared to grass. Therefore, animals can utilise higher energy content from feed.

One available option that is not investigated, but could be potentially be implemented by farmers are land use changes. Since farmers (particularly sheep and beef farmers) control a large proportion of the land in New Zealand they have the option to convert parts of farmland into forestry for carbon sinks. However, the impact towards on farm activities could be large, when farm land is converted into forestry. These impacts are difficult to quantify using representative farms, as the productivity of each hectare is not given. For example, one hectare may be more productive than other hectares on the farm, therefore quantifying the effects from land use change are difficult. Because land use changes significantly alter the farming practices they are not considered within the study.

After surveying the literature and deciding on appropriate mitigation strategies, each scenario for all representative farms are simulated using the OVERSEER nutrient budgets model, to attain physical results. Modelling is required to capture the different outcomes from mitigation strategies on representative farms, in particular, the non-linear effects on emissions from the addition of one or more mitigation strategies[13]. OVERSEER was chosen over other farm based models because; it is used widely by farmers around the country, relatively data un-intensive, uses national inventory

[13] For example, assume strategy A and strategy B achieve 5 and 10 percent reduction respectively when implemented singularly. When both strategies are implemented together it is postulated that the total effect on emissions will be less than 15 percent, due to the non-linearity of mitigation scenarios.

methods with farm specific data, calculates methane, carbon dioxide and nitrous oxide emissions, and also captures the non-linear relationships. OVERSEER accounts for changes in physical characteristics and extends the national inventory methodology to calculate emissions.

Physical results of different on-farm variables are difficult to relate to each other, as they are not in a standardised unit of account. Therefore, it is necessary to convert these physical results into financial impacts. To attain the financial impacts, price data are used to convert the physical results into financial results as per the partial budgeting methodology. Prices were drawn from a wide variety of sources, including academia, Ministry of Agriculture and Forestry, and fertiliser companies. Prices are multiplied by quantity changes to give financial results.

Analysis of physical impacts from OVERSEER is completed at the representative farm level. This farm level data is scaled to the regional level, and then the national level, through land use dedicated to each dairy farming region. Sheep and beef results were scaled using the number of real farms each representative farm signifies. Regional results were then summed by industry to give national totals. Financial results were scaled using the same methodology. A summary of the results are organised as follows; representative farm physical results (including emissions), representative farm financial results, regional physical results, regional financial results, and satisfying the Kyoto agreement.

Dairy farmers can effectively mitigate emissions through management strategies as shown by the representative farm mitigation results. The methane strategy which gave the highest absolute reduction in emissions was DME8. This involved a combination of mitigation strategies, including; reducing nitrogen fertiliser use to zero, importing additional feed, construction of a feed pad, and a reduction in animal numbers by 15 percent, while production was kept constant from the base case. For the nitrous oxide strategies, DNO6 gave the highest mitigation. This also involved a combination of mitigation strategies, including reducing nitrogen fertiliser use to zero, importing additional feed, and construction of a wintering pad. DME8 and DNO5 reduce emissions by approximately 50 and 45 percent respectively.

Sheep and beef farmers are not as effective at mitigating emissions through mitigation strategies, compared to dairy counterparts. The scenario that gave the highest mitigation was S&BME2, which involved reducing nitrogen fertiliser use to zero, and purchasing additional maize silage such that production remains constant from the base case. This strategy reduces emissions by around 7-8 percent, much less than the mitigation from representative dairy farms.

In terms of financial results, representative dairy farms can increase profit from implementing scenario DNO4, and some farms can profit from DME4 and DNO5. Under DNO4, the Canterbury representative farm can increase profit by $21,344 per annum (p.a.), larger than other representative dairy farms. The Northland representative dairy farm has the lowest profit increase, equal to $3,250 p.a. through DNO4. Depending on the level of the fertiliser use (under the base case), the magnitude of profit loss will be different for representative farms. Those representative farms that apply large amounts of nitrogen fertiliser are financially affected through a decrease in production when nitrogen fertiliser is used. High fertiliser usage translates into reduced pasture growth, and hence production. If the Southland representative farm stopped using nitrogen fertiliser, it would lose $72,121 p.a.

Sheep and beef representative farms cannot attain as high profit increases compared to dairy counterparts. The scenario that gave the highest profit increase was scenario S&BNO2. This was a relatively simple mitigation strategy, reduce nitrogen fertiliser use to zero with no other offsetting actions. Two sheep and beef representative farms already apply no nitrogen fertiliser. However, the level of financial profit ranges from $164 to $3,691 p.a. for the Waikato/BOP and Canterbury hill country representative farms respectively. This is much lower than the financial results for the dairy sector.

National results show that scenario DNO6 has the highest mitigation, equivalent to 7,754 thousand tons of CO_2-e or 47.7 percent of national dairy emissions. This involves a combination of various mitigation strategies, including reducing nitrogen fertiliser use to zero, purchasing additional maize silage to keep production constant, constructing a wintering pad, and the application DCD. For the sheep and beef sector, the strategy that has the highest mitigation if implemented nationally is S&BME2,

equivalent to 736 thousand tons of CO_2-e or 3.6 percent of sheep and beef emissions. This strategy involves reducing nitrogen fertiliser use to zero, purchasing additional feed to keep production constant, and construction of a wintering pad for cattle.

Nationally by implementing DNO4, dairy farmers can profit by a total of $71 million p.a. The Waikato/BOP region can profit by around $36 p.a. million from implementing scenario DNO4. Because there are fewer dairy farms within the Canterbury region, the increase in regional profit from DNO4 is only $10 million p.a. This is in contrast to other measures where the representative Canterbury farm attained the highest profit. Based on the assumptions within this analysis, it is recommended that dairy farmers implement DNO4. For the sheep and beef sector, farmers can increase profit by $11.8 million p.a. from implementing scenario S&BNO2. Hawkes Bay/Wairarapa hill country region has the largest share of this profit, at $2.1 million p.a. Based on the assumptions used within the sheep and beef analysis, it is recommended that the sheep and beef sector implements this strategy to increase profit. However, for the sector to meet emission targets it must look to mitigation options outside the scope of this study.

With the imposition of the ETS, and international Kyoto agreement, monetary goals will not be the sole objective to satisfy. The introduction of emissions targets will require farmers to alter current farming practices reduce emissions. The alternative (to altering current farming practices) is to purchase carbon credits that enable to owner to emit an additional ton of CO_2-e emissions. Within the dairy sector, 41 percent of dairy farmers are required to alter current farming practices to meet Kyoto targets for the sector. In contrast, the sheep and beef sector requires 461 percent of farms to alter current farming practices to meet the Kyoto target for the sector, which is implausible in practice. Financially, dairy farmers increase profit by $21 million p.a. when meeting the Kyoto target.

There were issues encountered within the research process. Firstly, production did not increase with the application of DCD in OVERSEER for dairy representative farms. DCD retains more nitrogen within the cycle and therefore should increase production through additional pasture growth. This will not affect the DCD results for the dairy representative farms, but will affect the relative results compared to other mitigation strategies.

A second issue involved the sheep and beef representative farms. These farms are not based solely on geographical region, hence land use dedicated to sheep and beef farming cannot be used to scale representative farms for regional and national results. Therefore, to overcome this problem, the number of real farms each representative farm signifies is used to scale physical and financial results.

Finally, it is assumed that gains from each strategy are captured immediately. In reality the gains from a particular strategy will accrue over the year, of subsequent years. Furthermore, the impacts from changes in the farm management practices will have long-run impacts at the farm level.

5.2 Conclusions

The strength of this research is that it is simple, whilst providing a rich, detailed, story about what variables will change at the farm level given a mitigation scenario. Simplicity along with low barriers to entry makes the research easy to replicate, for any number of individual farms. Therefore, the individual farmer is able to replicate the research for individual circumstances that best reflect their own farming position. Furthermore, given the quality of the emissions calculation in OVERSEER, this research shows that OVERSEER could be used to account for farm level emissions in the ETS. If farmers were required to report emissions, a large time series database could be collected under a scheme, such as the ETS, that could give researchers greater insight into farm level mitigation of emissions.

With simplicity comes a gap in the research, where the study only accounts for emissions within the farm gate. This is based on the assumption that farmers will be accountable for their own emissions, while other industries will be accountable for their emissions. Therefore, national emissions may increase through these mitigation strategies, as on-farm savings are off-set by increased emissions from other industries, such as transport crop growing. Costs may also be affected as other industries reduce emissions. Impacts from other industries mitigating emissions are not factored into this research. Analysis of the supply chain would be required to determine impacts from agricultural mitigation on other industry‟s emissions.

There are two sections within the results, physical and financial results. Results are based on several assumptions, which are taken to simplify the analysis. Assumptions (explicit and implicit) included; price assumptions, unhindered access to capital, availability and the supply chain of maize silage, and the speed farmers around the country can implement mitigation strategies. In addition, it is assumed that farming land use does not change throughout the country. Therefore, based on these assumptions, the main findings from the physical results are that the dairy sector can reduce emissions to meet Kyoto targets using management mitigation strategies. The sheep and beef sector cannot meet Kyoto targets through analysed management strategies. Both sectors can increase profit from mitigation strategies.

Also, the analysis assumes that farmers make changes in steps. For example, reducing nitrogen fertiliser use by 50 percent, and then 100 percent. However, the optimal nitrogen fertiliser use (given the trade-offs faced) could be to reduce nitrogen fertiliser use somewhere between 50 and 100 percent. An improvement in modelling physical variables to infinitesimal steps would determine the optimal level given the trade-offs.

For future work, marginal cost curves could be created. Cost curves display the relationship between marginal cost and marginal mitigation of particular strategies. Currently, it is possible to make these curves, but the interpretation is ambiguous. Extending the cost curve idea, the addition of a third variable would give a 3-dimensional map to display the trade-offs that the farmer faces.

Additional, research is constantly being completed testing newly developed mitigation strategies. Once this research reaches sufficient levels, to be implemented at the farm level, these new strategies could be included in future studies. The most promising strategy is increased understanding of rumen microbiology, because such work will address the biosynthesis of methane by the archea. For this reason it remains the major unknown factor in the area of methane mitigation research, although it is the most likely area to find an effective solution. OVERSEER includes new techniques once they become available.

Future studies could take an alternative methodology and take a sample of farms, rather than using representative farms (and possibly narrow the scope of the study to a particular region). This has the advantage of going more in-depth, and would allow a detailed time series analysis if completed over multiple years for the same farms. Capturing these individual farm level changes over time would take a many years to come through in the representative farm data, since it is a combination of many different farms. Furthermore, individual farm analysis allows for case studies into the long term effects from reducing greenhouse gas emissions. Studies of long-term effects from mitigation strategies are yet to be completed.

Policymakers can take comfort from the dairy results of this study, where dairy farmers can meet Kyoto targets and increase profit. The opposite is true for the sheep and beef sector. Based on the assumptions, and results of the study, there would be less resistance from dairy farmers from implementing the ETS, while sheep and beef farmers would be more resistant to the policy. In terms of policy setup, due to the differences in mitigation between industries, policymakers should target the individual industry at the farm level. This study concludes that targeting emissions per unit of output is not a viable option, as lowering this ratio is difficult while reducing total emissions.

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Appendices

A.1 Dairy Sector

Table A.1: Methane scenario farm level impacts for the Northland dairy representative farm (2007/08)

	Base Case	DME 1	DME 2	DME 3	DME 4	DME 5	DME 6	DME 7	DM E8
Milksolids (t)	64.8	69.3	70.9	73.1	64.8	64.8	64.8	64.8	64.8
Cow numbers	244	257	263	269	244	232	220	190	190
Nitrogen fertiliser (t)	7.4	7.4	7.4	7.4	0	7.4	7.4	7.4	0
Purchased feed (t)	0	49	73	98	40	0	0	0	40
Methane emissions (tons of CO2-e)	551	600	610	620	409	536	520	480	337
Nitrous oxide emissions (tons of CO2-e)	295	312	314	315	168	293	279	258	131

Table A.2: Nitrous oxide scenario farm level impacts for the Northland dairy representative farm (2007/08)

	Base Case	DNO1	DNO2	DNO3	DNO4	DNO5	DNO6
Milksolids (t)	64.8	63.1	62.1	64.8	64.8	64.8	64.8
Cow numbers	244	239	233	244	244	244	244
Nitrogen fertiliser (t)	7.4	3.7	0	7.4	0	0	0
Purchased feed (t)	0	0	0	0	40	40	40
Methane emissions (tons of CO2-e)	551	539	527	551	424	422	426
Nitrous oxide emissions (tons of CO2-e)	295	269	241	251	178	187	151

Table A.3: Methane scenario farm level impacts for the Waikato dairy representative farm (2007/08)

	Base Case	DME 1	DME 2	DME 3	DME 4	DME 5	DME 6	DME 7	DM E8
Milksolids (t)	95.9	97.3	98.6	100	95.9	95.9	95.9	95.9	95.9
Cow numbers	292	308	324	340	292	277	263	248	248
Nitrogen fertiliser (t)	13.8	13.8	13.8	13.8	0	13.8	13.8	13.8	0
Purchased feed (t)	0	61.6	97.2	136	75	0	0	0	75
Methane emissions (tons of CO2-e)	620	647	664	681	400	603	587	570	351
Nitrous oxide emissions (tons of CO2-e)	339	340	341	343	120	329	321	312	94

Table A.4: Nitrous oxide scenario farm level impacts for the Waikato dairy representative farm (2007/08)

	Base Case	DNO1	DNO2	DNO3	DNO4	DNO5	DNO6
Milksolids (t)	95.9	92.2	89.2	95.9	95.9	95.9	95.9
Cow numbers	292	282	271	292	292	292	292
Nitrogen fertiliser (t)	13.8	6.9	0	13.8	0	0	0
Purchased feed (t)	0	0	0	0	75	75	75
Methane emissions (tons of CO2-e)	620	598	575	620	425	405	412
Nitrous oxide emissions (tons of CO2-e)	339	289	239	298	137	146	128

Table A.5: Methane scenario farm level impacts for the Taranaki dairy representative farm (2007/08)

	Base Case	DME 1	DME 2	DME 3	DME 4	DME 5	DME 6	DME 7	DM E8
Milksolids (t)	87.9	94.2	96.9	100	87.9	87.9	87.9	87.9	87.9
Cow numbers	265	281	290	298	265	252	239	225	225
Nitrogen fertiliser (t)	12.9	12.9	12.9	12.9	0	12.9	12.9	12.9	0
Purchased feed (t)	0	53	79.5	106	70	0	0	0	70
Methane emissions (tons of CO2-e)	561	592	607	621	358	547	532	517	318
Nitrous oxide emissions (tons of CO2-e)	314	320	323	326	115	307	299	291	94

Table A.6: Nitrous oxide scenario farm level impacts for the Taranaki dairy representative farm (2007/08)

	Base Case	DNO1	DNO2	DNO3	DNO4	DNO5	DNO6
Milksolids (t)	87.9	84.4	80.4	87.9	87.9	87.9	87.9
Cow numbers	265	254	244	265	265	265	265
Nitrogen fertiliser (t)	12.9	6.45	0	12.9	0	0	0
Purchased feed (t)	0	0	0	0	70	70	70
Methane emissions (tons of CO2-e)	561	538	516	561	383	368	338
Nitrous oxide emissions (tons of CO2-e)	314	267	220	273	133	147	109

Table A.7: Methane scenario farm level impacts for the LNI dairy representative farm (2007/08)

	Base Case	DME 1	DME 2	DME 3	DME 4	DME 5	DME 6	DME 7	DME 8
Milksolids (t)	114.4	121.9	125.7	129.6	114.4	114.4	114.4	114.4	114.4
Cow numbers	360	381	391	401	360	342	324	306	306
Nitrogen fertiliser (t)	14.3	14.3	14.3	14.3	0	14.3	14.3	14.3	0
Purchased feed (t)	0	72	108	144	78	0	0	0	78
Methane emissions (tons of CO2-e)	718	742	759	776	493	698	679	660	435
Nitrous oxide emissions (tons of CO2-e)	400	402	404	407	176	390	379	369	145

Table A.8: Nitrous oxide scenario farm level impacts for the LNI dairy representative farm (2007/08)

	Base Case	DNO1	DNO2	DNO3	DNO4	DNO5	DNO6
Milksolids (t)	114.4	111	107.6	114.4	114.4	114.4	114.4
Cow numbers	360	349	338	360	360	360	360
Nitrogen fertiliser (t)	14.3	7.15	0	14.3	0	0	0
Purchased feed (t)	0	0	0	0	78	78	78
Methane emissions (tons of CO2-e)	718	696	674	718	709	488	486
Nitrous oxide emissions (tons of CO2-e)	400	349	298	317	303	169	160

Table A.9: Methane scenario farm level impacts for the Canterbury dairy representative farm (2007/08)

	Base Case	DME 1	DME 2	DME 3	DME 4	DME 5	DME 6	DME 7	DME 8
Milksolids (t)	268.7	282.9	290.3	297.4	268.7	268.7	268.7	268.7	268.7
Cow numbers	682	715	731	747	682	648	614	551	551
Nitrogen fertiliser (t)	50.6	50.6	50.6	50.6	0	50.6	50.6	50.6	0
Purchased feed (t)	0	136	204.5	272	276	0	0	0	276
Methane emissions (tons of CO2-e)	1626	1718	1750	1782	867	1588	1550	1480	774
Nitrous oxide emissions (tons of CO2-e)	1035	1059	1064	1069	317	1015	995	958	269

Table A.10: Nitrous oxide scenario farm level impacts for the Canterbury dairy representative farm (2007/08)

	Base Case	DNO1	DNO2	DNO3	DNO4	DNO5	DNO6
Milksolids (t)	268.7	255.7	241.9	268.7	268.7	268.7	268.7
Cow numbers	682	648	615	682	682	682	682
Nitrogen fertiliser (t)	50.6	25.3	0	50.6	0	0	0
Purchased feed (t)	0	0	0	0	276	276	276
Methane emissions (tons of CO2-e)	1626	1546	1465	1626	1355	932	842
Nitrous oxide emissions (tons of CO2-e)	1035	853	671	821	516	372	309

Table A.11: Methane scenario farm level impacts for the Southland dairy representative farm (2007/08)

	Base Case	DME 1	DME 2	DME 3	DME 4	DME 5	DME 6	DME 7	DME 8
Milksolids (t)	196	209.6	214.5	221.1	196	196	196	196	196
Cow numbers	490	516	528	540	490	465.5	441	416.5	417
Nitrogen fertiliser (t)	25.9	25.9	25.9	25.9	0	25.9	25.9	25.9	0
Purchased feed (t)	0	98	147	196	141	0	0	0	141
Methane emissions (tons of CO2-e)	1107	1141	1198	1236	702	1083	1058	1034	629
Nitrous oxide emissions (tons of CO2-e)	634	671	697	712	229	622	609	596	191

Table A.12: Nitrous oxide scenario farm level impacts for the Southland dairy representative farm (2007/08)

	Base Case	DNO1	DNO2	DNO3	DNO4	DNO5	DNO6
Milksolids (t)	196	188.7	181.3	196	196	196	196
Cow numbers	490	472	454	490	490	490	490
Nitrogen fertiliser (t)	25.9	12.95	0	25.9	0	0	0
Purchased feed (t)	0	0	0	0	149	149	149
Methane emissions (tons of CO2-e)	1107	1066	1025	1107	735	626	621
Nitrous oxide emissions (tons of CO2-e)	634	541	448	488	243	230	203

Table A.13: Methane scenario farm level total CO_2 emissions for all dairy representative farms (2007/08)

	Base Case	DME 1	DME 2	DME 3	DME 4	DME 5	DME 6	DME 7	DME 8
Northland	847	912	924	935	577	836	799	738	468
Waikato	958	967	975	984	520	932	908	882	444
Taranaki	876	912	930	947	473	853	831	808	412
LNI	1118	1144	1163	1183	668	1088	1058	1029	580
Canterbury	2661	2777	2814	2850	1184	2603	2545	2438	1044
Southland	1741	1875	2046	2262	931	1705	1667	1630	820

Table A.14 Nitrous oxide scenario farm level total CO_2 emissions for all dairy representative farms (2007/08)

	Base Case	DNO1	DNO2	DNO3	DNO4	DNO5	DNO6
Northland	847	808	768	802	602	609	577
Waikato	958	887	814	918	562	551	540
Taranaki	876	805	736	834	516	515	447
LNI	1118	1045	972	1035	1012	657	646
Canterbury	2661	2399	2136	2447	1871	1304	1151
Southland	1741	1607	1473	1595	978	856	824

Table A.15: Additional costs / forgone revenue, for Northland representative dairy farm (2007/08)

	Wintering/ Feed pad costs (p.a.)	Maintenance costs (feed or winter pad)	DCD	Milksolids	Purchased feed	Total
DME4	-$5,154	-$2,440			-$6,000	-$13,594
DNO1				-$12,401		-$12,401
DNO2				-$20,433		-$20,433
DNO3			-$17,064			-$17,064
DNO4					-$6,000	-$6,000
DNO5	-$5,154	-$2,440			-$6,000	-$13,594
DNO6	-$5,154	-$2,440	-$17,064		-$6,000	-$30,658

Table A.16: Additional revenue / forgone costs, for Northland representative dairy farm (2007/08)

	Fertiliser	Smaller herd size	Total
DME4	$9,250		$9,250
DNO1	$4,625	$693	$5,318
DNO2	$9,250	$1,563	$10,813
DNO3			$ -
DNO4	$9,250		$9,250
DNO5	$9,250		$9,250
DNO6	$9,250		$9,250

Table A.17: Additional costs / forgone revenue, for Waikato representative dairy farm (2007/08)

	Wintering/ Feed pad costs (p.a.)	Maintenance costs (feed or winter pad)	DCD	Milksolids	Purchased feed	Total
DME4	-$6,168	-$2,920			-$11,250	-$20,338
DNO1				-$27,328		-$27,328
DNO2				-$49,803		-$49,803
DNO3			-$16,274			-$16,274
DNO4					-$11,250	-$11,250
DNO5	-$6,168	-$2,920			-$11,250	-$20,338
DNO6	-$6,168	-$2,920	-$16,274		-$11,250	-$36,612

Table A.18: Additional revenue / forgone costs, for Waikato representative dairy farm (2007/08)

	Fertiliser	Smaller herd size	Total
DME4	$17,250		$17,250
DNO1	$8,625	$1,388	$10,013
DNO2	$17,250	$3,032	$20,282
DNO3			$ -
DNO4	$17,250		$17,250
DNO5	$17,250		$17,250
DNO6	$17,250		$17,250

Table A.19: Additional costs / forgone revenue, for Taranaki representative dairy farm (2007/08)

	Wintering/ Feed pad costs (p.a.)	Maintenance costs (feed or winter pad)	DCD	Milksolids	Purchased feed	Total
DME4	-$5,598	-$2,650			-$10,500	-$18,748
DNO1				-$25,440		-$25,440
DNO2				-$55,539		-$55,539
DNO3			-$15,168			-$15,168
DNO4					-$10,500	-$10,500
DNO5	-$5,598	-$2,650			-$10,500	-$18,748
DNO6	-$5,598	-$2,650	-$15,168		-$10,500	-$33,916

Table A.20: Additional revenue / forgone costs, for Taranaki representative dairy farm (2007/08)

	Fertiliser	Smaller herd size	Total
DME4	$16,125		$16,125
DNO1	$8,063	$1,537	$9,600
DNO2	$16,125	$3,055	$19,180
DNO3			$ -
DNO4	$16,125		$16,125
DNO5	$16,125		$16,125
DNO6	$16,125		$16,125

Table A.21: Additional costs / forgone revenue, for LNI representative dairy farm (2007/08)

	Wintering/ Feed pad costs (p.a.)	Maintenance costs (feed or winter pad)	DCD	Milksolids	Purchased feed	Total
DME4	-$7,604	-$3,600			-$11,700	-$22,904
DNO1				-$25,173		-$25,173
DNO2				-$50,301		-$50,301
DNO3			-$20,540			-$20,540
DNO4					-$11,700	-$11,700
DNO5	-$7,604	-$3,600			-$11,700	-$22,903
DNO6	-$7,604	-$3,600	-$20,540		-$11,700	-$43,443

Table A.22: Additional revenue / forgone costs, for LNI representative dairy farm (2007/08)

	Fertiliser	Smaller herd size	Total
DME4	$17,732		$17,732
DNO1	$8,866	$1,235	$10,101
DNO2	$17,732	$2,550	$20,282
DNO3			$ -
DNO4	$17,732		$17,732
DNO5	$17,732		$17,732
DNO6	$17,732		$17,732

Table A.23: Additional costs / forgone revenue, for Canterbury representative dairy farm (2007/08)

	Wintering/ Feed pad costs (p.a.)	Maintenance costs (feed or winter pad)	DCD	Milksolids	Purchased feed	Total
DME4		-$6,820			-$41,400	-$48,220
DNO1				-$96,746		-$96,746
DNO2				-$199,243		-$199,243
DNO3			-$32,074			-$32,074
DNO4					-$41,400	-$41,400
DNO5	-$14,406	-$6,820			-$41,400	-$62,626
DNO6	-$14,406	-$6,820	-$32,074		-$41,400	-$94,700

Table A.24: Additional revenue / forgone costs, for Canterbury representative dairy farm (2007/08)

	Fertiliser	Smaller herd size	Total
DME4	$62,744		$62,744
DNO1	$31,372	$5,102	$36,474
DNO2	$62,744	$10,594	$73,338
DNO3			$ -
DNO4	$62,744		$62,744
DNO5	$62,744		$62,744
DNO6	$62,744		$62,744

Table A.25: Additional costs / forgone revenue, for Southland representative dairy farm (2007/08)

	Wintering pad costs (p.a.)	Maintenance costs (feed or winter pad)	DCD	Milksolids	Purchased feed	Total
DME4		-$4,900			-$21,150	-$26,050
DNO1				-$54,402		-$54,402
DNO2				-$109,436		-$109,436
DNO3			-$32,864			-$32,864
DNO4					-$21,150	-$21,150
DNO5	-$10,350	-$4,900			-$21,150	-$36,400
DNO6	-$10,350	-$4,900	-$32,864		-$21,150	-$69,264

Table A.26: Additional revenue / forgone costs, for Southland representative dairy farm (2007/08)

	Fertiliser	Smaller herd size	Total
DME4	$32,375		$32,375
DNO1	$16,188	$2,376	$18,563
DNO2	$32,375	$4,940	$37,315
DNO3			$ -
DNO4	$32,375		$32,375
DNO5	$32,375		$32,375
DNO6	$32,375		$32,375

A.2 Sheep and Beef Sector

Table A.27: Methane and nitrous oxide scenario farm level impacts for the Canterbury Marlborough Breeding & Finishing sheep and beef representative farm (2006/07)

	Base Case	**S&B ME1**	**S&B ME2**	**S&B ME3**	**S&B ME4**	**S&B ME5**	**S&B NO1**	**S&B NO2**	**S&B NO3**
Production change (%)		0.0	0.0	22.7	45.3	68.1	-0.3	-0.6	2.8
Cattle numbers	808	808	808	991	1174	1358	806	803	831
Sheep numbers	2877	2877	2877	3530	4180	4836	2868	2860	2958
Nitrogen fertiliser (t)	1.9	0	0	1.9	1.9	1.9	0.95	0	1.9
Purchased feed (t)	0	10	10	369	737	1106	0	0	0
Methane emissions (tons of CO2-e)	982	952	948	1161	1340	1519	978	975	1009
Nitrous oxide emissions (tons of CO2-e)	384	359	358	421	457	494	378	371	288

Table A.28: Methane and nitrous oxide scenario farm level impacts for the Canterbury Marlborough Hill Country sheep and beef representative farm (2006/07)

	Base Case	**S&B ME1**	**S&B ME2**	**S&B ME3**	**S&B ME4**	**S&B ME5**	**S&B NO1**	**S&B NO2**	**S&B NO3**
Production change (%)		0.0	0.0	22.5	45.1	67.6	-0.6	-1.2	6.5
Cattle numbers	1952	1952	1952	2391	2832	3272	1940	1929	2079
Sheep numbers	3431	3431	3431	4203	4978	5750	3410	3390	3654
Nitrogen fertiliser (t)	5.5	0	0	5.5	5.5	5.5	2.75	0	5.5
Purchased feed (t)	0	30	30	538	1077	1615	0	0	0
Methane emissions (tons of CO2-e)	1436	1351	1337	1696	1957	2217	1428	1418	1530
Nitrous oxide emissions (tons of CO2-e)	585	514	509	640	693	746	567	548	458

Table A.29: Methane and nitrous oxide scenario farm level impacts for the Central NI sheep and beef representative farm (2006/07)

	Base Case	S&B ME1	S&B ME2	S&B ME3	S&B ME4	S&B ME5	S&B NO1	S&B NO2	S&B NO3
Production change (%)		0.0	0.0	22.5	44.9	67.4	-0.2	-0.4	3.2
Cattle numbers	2002	2002	2002	2452	2901	3351	1998	1994	2066
Sheep numbers	3414	3414	3414	4182	4947	5715	3407	3400	3523
Nitrogen fertiliser (t)	1.6	0	0	1.6	1.6	1.6	0.8	0	1.6
Purchased feed (t)	0	9	9	542	1083	1625	0	0	0
Methane emissions (tons of CO2-e)	1449	1424	1424	1711	1972	2233	1447	1444	1495
Nitrous oxide emissions (tons of CO2-e)	570	549	548	624	678	733	565	559	546

Table A.30: Methane and nitrous oxide scenario farm level impacts for the Eastern Lower NI Intensive sheep and beef representative farm (2006/07)

	Base Case	S&B ME1	S&B ME2	S&B ME3	S&B ME4	S&B ME5	S&B NO1	S&B NO2	S&B NO3
Production change (%)		0.0	0.0	22.5	45.0	67.5	-0.3	-0.5	2.1
Cattle numbers	1620	1620	1620	1985	2349	2714	1615	1612	1654
Sheep numbers	2450	2450	2450	3001	3553	4104	2443	2438	2501
Nitrogen fertiliser (t)	1.7	0	0	1.7	1.7	1.7	0.85	0	1.7
Purchased feed (t)	0	10	10	407	814	1221	0	0	0
Methane emissions (tons of CO2-e)	1086	1059	1058	1283	1479	1676	1084	1081	1109
Nitrous oxide emissions (tons of CO2-e)	431	408	431	471	512	552	425	419	355

Table A.31: Methane and nitrous oxide scenario farm level impacts for the Gisborne Hill Country sheep and beef representative farm (2006/07)

	Base Case	S&BME 3	S&BME 4	S&BME 5	S&BNO 3
Production change (%)		21.3	42.6	63.9	0.0
Cattle numbers	3429	4159	4890	5620	3429
Sheep numbers	4041	4902	5762	6623	4041
Nitrogen fertiliser (t)	0	0	0	0	0
Purchased feed (t)	0	747	1494	2241	0
Methane emissions (tons of CO2-e)	2100	2439	2779	0	2100
Nitrous oxide emissions (tons of CO2-e)	825	892	959	0	744

Table A.32: Methane and nitrous oxide scenario farm level impacts for the Hawkes Bay Wairarapa Hill Country sheep and beef representative farm (2006/07)

	Base Case	S&B ME1	S&B ME2	S&B ME3	S&B ME4	S&B ME5	S&B NO1	S&B NO2	S&B NO3
Production change (%)		0.0	0.0	21.5	43.0	64.5	-0.3	-0.6	2.4
Cattle numbers	1635	1635	1635	1987	2338	2690	1630	1625	1674
Sheep numbers	4343	4343	4343	5277	6210	7144	4330	4317	4447
Nitrogen fertiliser (t)	3.1	0	0	3.1	3.1	3.1	1.55	0	3.1
Purchased feed (t)	0	17	17	598	1196	1793	0	0	0
Methane emissions (tons of CO2-e)	1677	1624	1619	1951	2225	2498	1672	1666	1717
Nitrous oxide emissions (tons of CO2-e)	664	621	619	718	771	825	653	642	534

Table A.33: Methane and nitrous oxide scenario farm level impacts for the Lower NI - West sheep and beef representative farm (2006/07)

	Base Case	S&B ME1	S&B ME2	S&B ME3	S&B ME4	S&B ME5	S&B NO1	S&B NO2	S&B NO3
Production change (%)		0.0	0.0	23.7	47.4	71.0	-0.3	-0.5	2.3
Cattle numbers	838	838	838	1037	1235	1433	835	834	857
Sheep numbers	1620	1620	1620	2004	2388	2770	1615	1612	1657
Nitrogen fertiliser (t)	1	0	0	1	1	1	0.5	0	1
Purchased feed (t)	0	6	6	246	492	737	0	0	0
Methane emissions (tons of CO2-e)	625	610	608	750	875	1000	623	622	639
Nitrous oxide emissions (tons of CO2-e)	246	232	232	272	300	326	242	238	194

Table A.34: Methane and nitrous oxide scenario farm level impacts for the Northland sheep and beef representative farm (2006/07)

	Base Case	S&B ME1	S&B ME2	S&B ME3	S&B ME4	S&B ME5	S&B NO1	S&B NO2	S&B NO3
Production change (%)		0.0	0.0	20.6	41.3	62.0	-0.6	-1.1	0.7
Cattle numbers	2367	2367	2367	2855	3345	3835	2353	2341	2384
Sheep numbers	785	785	785	947	1109	1272	780	776	790
Nitrogen fertiliser (t)	3.1	0	0	3.1	3.1	3.1	1.55	0	3.1
Purchased feed (t)	0	17	17	315	630	946	0	0	0
Methane emissions (tons of CO2-e)	906	850	851	1039	1172	0	901	896	912
Nitrous oxide emissions (tons of CO2-e)	381	337	336	405	430	0	370	359	347

Table A.35: Methane and nitrous oxide scenario farm level impacts for the Otago Dry Hill sheep and beef representative farm (2006/07)

	Base Case	S&B ME1	S&B ME2	S&B ME3	S&B ME4	S&B ME5	S&B NO1	S&B NO2	S&B NO3
Production change (%)		0.0	0.0	24.0	48.0	72.0	-0.4	-0.7	9.9
Cattle numbers	870	870	870	1079	1288	1496	867	864	956
Sheep numbers	5654	5654	5654	7011	8368	9725	5631	5614	6214
Nitrogen fertiliser (t)	3.5	0	0	3.5	3.5	3.5	1.75	0	3.5
Purchased feed (t)	0	19	19	652	1305	1957	0	0	0
Methane emissions (tons of CO2-e)	1646	1594	1584	1982	2316	2652	1640	1634	1810
Nitrous oxide emissions (tons of CO2-e)	646	600	596	718	790	862	634	620	484

Table A.36: Methane and nitrous oxide scenario farm level impacts for the South Island High Country sheep and beef representative farm (2006/07)

	Base Case	S&BME 3	S&BME 4	S&BME 5	S&BNO 3
Production change (%)		23.2	46.4	69.6	0.0
Cattle numbers	1400	1725	2050	2374	1400
Sheep numbers	7614	9380	11147	12913	7614
Nitrogen fertiliser (t)	0	0	0	0	0
Purchased feed (t)	0	901	1803	2704	0
Methane emissions (tons of CO2-e)	700	845	990	0	716
Nitrous oxide emissions (tons of CO2-e)	280	312	344	0	234

Table A.37: Methane and nitrous oxide scenario farm level impacts for the Southland South Otago Hill sheep and beef representative farm (2006/07)

	Base Case	S&B ME1	S&B ME2	S&B ME3	S&B ME4	S&B ME5	S&B NO1	S&B NO2	S&B NO3
Production change (%)		0.0	0.0	25.3	50.5	75.8	-0.4	-0.8	3.4
Cattle numbers	817	817	817	1024	1230	1436	814	810	845
Sheep numbers	5250	5250	5250	6578	7901	9230	5229	5208	5429
Nitrogen fertiliser (t)	3.6	0	0	3.6	3.6	3.6	1.8	0	3.6
Purchased feed (t)	0	20	20	607	1213	1820	0	0	0
Methane emissions (tons of CO2-e)	1455	1405	1398	1782	2108	2434	1450	1444	1505
Nitrous oxide emissions (tons of CO2-e)	566	521	519	638	710	782	553	541	395

Table A.38: Methane and nitrous oxide scenario farm level impacts for the Southland South Otago Intensive Finishing sheep and beef representative farm (2006/07)

	Base Case	S&B ME1	S&B ME2	S&B ME3	S&B ME4	S&B ME5	S&B NO1	S&B NO2	S&B NO3
Production change (%)		0.0	0.0	25.4	50.8	76.2	-0.2	-0.5	2.5
Cattle numbers	135	135	135	169	204	238	135	134	138
Sheep numbers	2556	2556	2556	3205	3854	4504	2551	2543	2620
Nitrogen fertiliser (t)	1	0	0	1	1	1	0.5	0	1
Purchased feed (t)	0	5	5	269	538	807	0	0	0
Methane emissions (tons of CO2-e)	644	631	629	789	934	1080	642	641	660
Nitrous oxide emissions (tons of CO2-e)	243	231	230	275	307	339	239	236	168

Table A.39: Methane and nitrous oxide scenario farm level impacts for the Waikato BOP Intensive sheep and beef representative farm (2006/07)

	Base Case	S&B ME1	S&B ME2	S&B ME3	S&B ME4	S&B ME5	S&B NO1	S&B NO2	S&B NO3
Production change (%)		0.0	0.0	24.0	48.0	72.0	-0.3	-0.6	2.3
Cattle numbers	1413	1413	1413	1752	2091	2430	1409	1405	1445
Sheep numbers	1393	1393	1393	1727	2062	2396	1389	1385	1425
Nitrogen fertiliser (t)	1.2	0	0	1.2	1.2	1.2	0.6	0	1.2
Purchased feed (t)	0	7	7	281	561	842	0	0	0
Methane emissions (tons of CO2-e)	700	682	681	845	990	0	698	696	716
Nitrous oxide emissions (tons of CO2-e)	280	265	264	312	344	0	276	272	234

Table A.40: Additional costs / forgone revenue, for the Canterbury Marlborough Breeding & Finishing representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&BNO1	-$787						-$787
S&BNO2	-$1,573						-$1,573
S&BNO3		-$413	-$59,724				-$60,137
S&BME1				-$1,500			-$1,500
S&BME2				-$1,500	-$17,068	-$8,080	-$26,648

Table A.41: Additional revenue / forgone costs, for the Canterbury Marlborough Breeding & Finishing representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$44	$1,188		$1,232
S&BNO2	$89	$2,375		$2,464
S&BNO3			$7,341	$7,341
S&BME1		$2,375		$2,375
S&BME2		$2,375		$2,375

Table A.42: Additional costs / forgone revenue, for the Canterbury Marlborough Hill Country representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&B NO1	-$1,698						-$1,698
S&B NO2	-$3,396						-$3,396
S&B NO3		-$1,148	-$220,726				-$221,874
S&B ME1				-$7,750			-$7,750
S&B ME2				-$7,750	-$41,232	-$19,520	-$68,502

Table A.43: Additional revenue / forgone costs, for the Canterbury Marlborough Hill Country representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$106	$3,438		$3,543
S&BNO2	$212	$6,875		$7,087
S&BNO3			$18,397	$18,397
S&BME1		$6,875		$6,875
S&BME2		$6,875		$6,875

Table A.44: Additional costs / forgone revenue, for the Central NI representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&BNO1	-$616						-$616
S&BNO2	-$1,232						-$1,232
S&BNO3		-$693	-$100,330				-$101,023
S&BME1				-$2,200			-$2,200
S&BME2				-$2,200	-$42,289	-$20,020	-$64,509

Table A.45: Additional revenue / forgone costs, for the Central NI representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$43	$1,000		$1,043
S&BNO2	$87	$2,000		$2,087
S&BNO3			$9,853	$9,853
S&BME1		$2,000		$2,000
S&BME2		$2,000		$2,000

Table A.46: Additional costs / forgone revenue, for the Eastern Lower NI Intensive representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&BNO1	-$1,071						-$1,071
S&BNO2	-$1,785						-$1,785
S&BNO3		-$278	-$54,826				-$55,104
S&BME1				-$2,250			-$2,250
S&BME2				-$2,250	-$34,220	-$16,200	-$52,670

Table A.47: Additional revenue / forgone costs, for the Eastern Lower NI Intensive representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$40	$1,063		$1,102
S&BNO2	$66	$2,125		$2,191
S&BNO3			$7,497	$7,497
S&BME1		$2,125		$2,125
S&BME2		$2,125		$2,125

Table A.48: Additional costs / forgone revenue, for the Gisborne Hill Country representative sheep and beef farm (2006/07)

	Larger herd	DCD	Wintering pad	Maintaining winter pad	Total
S&BNO3	$0	-$129,718			-$129,718
S&BME2			-$72,431	-$34,290	-$106,721

Table A.49: Additional costs / forgone revenue, for the Hawkes Bay Wairarapa Hill Country representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&BNO1	-$1,085						-$1,085
S&BNO2	-$2,170						-$2,170
S&BNO3		-$426	-$98,592				-$99,018
S&BME1				-$4,350			-$4,350
S&BME2				-$4,350	-$34,536	-$16,350	-$55,236

Table A.50: Additional revenue / forgone costs, for the Hawkes Bay Wairarapa Hill Country representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$53	$1,938		$1,991
S&BNO2	$107	$3,875		$3,982
S&BNO3			$8,679	$8,679
S&BME1		$3,875		$3,875
S&BME2		$3,875		$3,875

Table A.51: Additional costs / forgone revenue, for the Lower NI - West representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&BNO1	-$488						-$488
S&BNO2	-$813						-$813
S&BNO3		-$209	-$32,864				-$33,073
S&BME1				-$1,300			-$1,300
S&BME2				-$1,300	-$17,701	-$8,380	-$27,381

Table A.52: Additional revenue / forgone costs, for the Lower NI - West representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$27	$625		$652
S&BNO2	$45	$1,250		$1,295
S&BNO3			$3,739	$3,739
S&BME1		$1,250		$1,250
S&BME2		$1,250		$1,250

Table A.53: Additional costs / forgone revenue, for the Northland representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&BNO1	-$1,257						-$1,257
S&BNO2	-$2,305						-$2,305
S&BNO3		-$79	-$49,612				-$49,691
S&BME1				-$4,350			-$4,350
S&BME2				-$4,350	-$49,999	-$23,670	-$78,019

Table A.54: Additional revenue / forgone costs, for the Northland representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$68	$1,938		$2,005
S&BNO2	$124	$3,875		$3,999
S&BNO3			$1,467	$1,467
S&BME1		$3,875		$3,875
S&BME2		$3,875		$3,875

Table A.55: Additional costs / forgone revenue, for the Otago Dry Hill representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&BNO1	-$1,560						-$1,560
S&BNO2	-$2,730						-$2,730
S&BNO3		-$1,478	-$316,000				-$317,478
S&BME1				-$4,950			-$4,950
S&BME2				-$4,950	-$18,377	-$8,700	-$32,027

Table A.56: Additional revenue / forgone costs, for the Otago Dry Hill representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$60	$2,188		$2,247
S&BNO2	$105	$4,375		$4,480
S&BNO3			$38,611	$38,611
S&BME1		$4,375		$4,375
S&BME2		$4,375		$4,375

Table A.57: Additional costs / forgone revenue, for the South Island High Country representative sheep and beef farm (2006/07)

	Larger herd	DCD	Wintering pad	Maintaining winter pad	Total
S&BNO3	$0	-$1,660,264			-$1,660,264
S&BME2			-$29,572	-$14,000	-$43,572

Table A.58: Additional costs / forgone revenue, for the Southland South Otago Hill representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&BNO1	-$1,508						-$1,508
S&BNO2	-$3,016						-$3,016
S&BNO3		-$606	-$114,234				-$114,840
S&BME1				-$5,000			-$5,000
S&BME2				-$5,000	-$17,258	-$8,170	-$30,428

Table A.59: Additional revenue / forgone costs, for the Southland South Otago Hill representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$71	$2,250		$2,321
S&BNO2	$143	$4,500		$4,643
S&BNO3			$12,818	$12,818
S&BME1		$4,500		$4,500
S&BME2		$4,500		$4,500

Table A.60: Additional costs / forgone revenue, for the Southland South Otago Intensive Finishing representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&BNO1	-$395						-$395
S&BNO2	-$987						-$987
S&BNO3		-$309	-$30,652				-$30,961
S&BME1				-$1,500			-$1,500
S&BME2				-$1,500	-$2,852	-$1,350	-$5,702

Table A.61: Additional revenue / forgone costs, for the Southland South Otago Intensive Finishing representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$25	$625		$650
S&BNO2	$62	$1,250		$1,312
S&BNO3			$4,933	$4,933
S&BME1		$1,250		$1,250
S&BME2		$1,250		$1,250

Table A.62: Additional costs / forgone revenue, for the Waikato/BOP representative sheep and beef farm (2006/07)

	Prod. change	Larger herd	DCD	Purchased feed	Wintering pad	Maintaining winter pad	Total
S&BNO1	-$694						-$694
S&BNO2	-$1,387						-$1,387
S&BNO3		-$197	-$39,500				-$39,697
S&BME1				-$1,050			-$1,050
S&BME2				-$1,050	-$ 29,847	-$14,130	-$45,027

Table A.63: Additional revenue / forgone costs, for the Waikato/BOP representative sheep and beef farm (2006/07)

	Smaller herd size	Fertiliser	Production change	Total
S&BNO1	$25	$750		$775
S&BNO2	$51	$1,500		$1,551
S&BNO3			$5,318	$5,318
S&BME1		$1,500		$1,500
S&BME2		$1,500		$1,500