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AGRICULTURAL GREENHOUSE GAS
Research Centre

On-farm options to reduce agricultural GHG emissions in New Zealand

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Report to the Biological Emissions Reference Group

The Biological Emissions Reference Group (BERG) is a partnership between New Zealand's agricultural sector and the Government. BERG has been tasked with collaboratively establishing a robust and agreed evidence base on opportunities available, now and in future, to reduce biological greenhouse gas emissions (methane and nitrous oxide) on-farm. In doing so, it will consider the costs, benefits, and barriers.

This report is one of several commissioned by BERG to build this initial evidence base to inform any future actions or policies. If a policy process were to commence following this analysis, further work would be required. BERG welcomes this report and supports the analysis contained within it. However, it is out-of-scope of the BERG's Terms of Reference to express a preference for any specific options identified or recommended by the author(s).

BERG is comprised of the following voting members: Beef + Lamb New Zealand, Dairy NZ Limited, Deer Industry New Zealand, Federated Farmers of New Zealand, The Fertiliser Association of New Zealand, Fonterra, Horticulture New Zealand, Ministry for Primary Industries, and Ministry for the Environment.

The following organisations are observers of BERG: Climate Change Iwi Leaders Group, Meat Industry Association of New Zealand, Ministry of Business, Innovation and Employment, Ministry of Foreign Affairs & Trade, and The Treasury.

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Executive summary

This report provides an overview of currently available options to reduce (mitigate) New Zealand's biological GHG emissions. The vast majority of those emissions comes from cattle and sheep.

Mitigation options involving changes in farm systems, including potential land use change, were quantified for a set of model farms that represent regional average dairy farms and various regional average sheep and beef systems. Off-farm emissions embedded in supplementary feeds were included in our analysis where relevant, mainly for the dairy sector.

We find various options that would reduce biological GHG emissions moderately in both the dairy and sheep & beef sectors without reducing the profitability of our model farms, even though some options reduce total production. Other interventions, especially those resulting in deep emission reductions, would have significant negative impacts on both production and profitability. Further analysis is needed as to why options that appear profitable in their own right are not taken up more widely. This could also identify mechanisms by which greater uptake could be promoted.

Environmental and economic outcomes were evaluated using the two farm-scale models FARMAX and OVERSEER®. The two models differ somewhat in their assumptions regarding the metabolisable energy content of key animal feeds and the feeding levels required to achieve given levels of animal production. The combination of these two models, together with details of how farm systems and mitigation scenarios are characterised in the models, means that results need careful interpretation. The implications of these differences are discussed in the body of the report. Known issues in the OVERSEER® GHG calculations mean that emissions for dairy systems are overestimated by about 15% and hence the implied carbon cost of mitigation[1] is underestimated by almost the same amount. These issues in GHG estimation do not affect the relative efficacy of the different modelled mitigation options.

The modelling only considered the biophysical feasibility and environmental and economic consequences at the farm level. The models do not consider changing risks as a result of climate or market variability or limitations in farmer skills, or the diversity of actual farms within a region. In some cases, such issues could constitute a significant barrier to implementation. At the same time, our mitigation interventions have not sought to optimise farms with regard to GHG emissions and profitability; combining interventions and optimising farm systems could reduce costs relative to the single interventions that form the basis of our analysis.

Farmer behaviour in response to price or other policy signals was not modelled and national benefits or costs arising from widespread implementation of any mitigation action were not modelled. However, we provide commentary where such considerations appear particularly relevant. While interventions that reduce the total amount of dry matter consumption generally have co-benefits with water quality, the extent to which freshwater reform might in fact drive some of these interventions even in the absence of climate policies was not explored.

The interventions explored in the study are *not necessarily additive;* the modelling was on individual scenarios, not system optimisation. The total mitigation potential is not the sum of individual mitigation options as some interventions are strict alternatives (e.g. some interventions reduce stocking rates whereas others increase them). Combining interventions into lower GHG emitting and profitable farm systems requires an optimisation approach that considers individual farm characteristics, farmer objectives and external constraints.

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[1] The carbon cost of mitigation, expressed in $/tCO_2e$, is defined as the amount of emissions reduction achieved by an intervention divided by the net economic cost (or benefit) to farmers of taking this action. If the carbon cost of mitigation for a specific intervention is lower than a hypothetical GHG emissions price, this indicates that this action to reduce GHG emissions would result in lower costs for farmers than if farmers did not change their operations and simply paid the price of their emissions.

The farm systems investigated here were based on industry and regional "averages" and were not meant to represent any specific real-life individual farms. There are almost 25,000 commercial pastoral farms in New Zealand and each one (along with its manager) is unique. It is important to remember that optimum mitigation scenarios with their associated farm production and profitability characteristics will be farm-specific, even for apparently similar farms.

With these perspectives in mind, the following key findings emerge from our assessment.

For the dairy sector:

- Individual interventions other than on-farm forestry would reduce absolute biological GHG emissions by 2-10%. In some instances, the amount of emission reduction depends on whether and how off-farm emissions (embedded in bought-in feed) are accounted for, including whether emissions occurring overseas are considered. Options involving on-farm forestry can achieve much bigger emission reductions but outcomes depend strongly on whether the 'safe carbon' potential or the full sequestration potential (e.g. from conservation forests) is considered.
- Implications for profitability of those interventions vary widely, from strongly negative with implied carbon costs of mitigation well in excess of $100/tCO_2e$, to positive (i.e. they should increase profitability of the farm even without consideration of climate benefits). The most costly options generally are those involving on-farm forestry despite a range of different approaches tested. The only exception to this is where forests are planted on marginal land only but actual costs and benefits of this will vary considerably between individual farms.
- Reducing stocking rates and improving productivity per animal consistently reduces GHG emissions by up to 10% and increases farm profitability. Emissions intensity would also reduce. This finding is robust across different farm systems and applies even if pasture quality is assumed to decline somewhat as a result of this change. Economic benefits are higher when payouts for milk solids are lower. Some farmers have already moved in this direction, but the limited adoption of this approach to date indicates significant barriers, including the need for enhanced farmer skill and increased risk to farmers of reduced pasture quality. Improved understanding of farmer and industry attitudes and of barriers to a more systematic adoption would be necessary to more fully understand the scale at which this apparent no-cost mitigation option could be implemented across the dairy industry.
- Switching to Once-A-Day (OAD) milking in principle could allow a reduction in GHG emissions (of around 5-10%) through reducing production without reducing profitability, given that input costs (in particular labour) would also drop. However, experience is as yet limited with this approach in New Zealand. We have therefore not attempted to model *likely* outcomes but rather provide indicative results that demonstrate how much production per cow could drop when switching to OAD milking for the farm to retain the same profitability as a Twice-A-Day milking farm. Results depend strongly on assumptions including payouts for milk solids and reductions in labour costs but provide a framework for considering this option. Whether such outcomes are in fact feasible and the implications for New Zealand's dairy industry if implemented at scale require further investigation.
- Other mitigation interventions such as the use of low protein supplementary feeds, removal of nitrogen fertiliser or removal of summer crops have mixed economic implications across different systems and regions. Our results provide some indications regarding their potential regional impacts, but outcomes are likely to vary significantly across individual farms.

For the sheep & beef sector:

- Options to reduce biological GHG emissions are more limited for the sheep & beef sector than for the dairy sector, given the lower management intensity. The main option consists of integrating forestry into farm operations. This can achieve significant emission reductions (beyond 100%) especially if forests are planted for conservation purposes.

- Mitigation approaches involving forestry reduce the profitability of the average sheep & beef farm, but by much less than for the average dairy farm. Implied carbon costs of mitigation range from less than \$10/tCO_2e to \$35-\$45/tCO_2e, depending on approach to forestry. Given the heterogeneous nature of the sheep & beef sector, there will be a significant fraction of farms for which the introduction of forestry would be profitable in its own right (especially if limited to marginal land). However, committing large land areas to forestry reduces flexibility in how the farm is managed, and generally requires an intensification of the remaining pastoral enterprise to minimise overall costs, which requires increased skill. Both aspects can present significant barriers to widespread implementation.
- Reducing stocking rates while improving productivity per animal in intensive finishing systems results in minor (2-5%) emission reductions, but a potentially significant increase in profitability of 16-28%. Such changes might happen over time even under business-as-usual if the sheep and beef sector is to remain viable in some areas; our modelling suggests that such trends could be accelerated considerably and result in significant economic benefits. Barriers to universal adoption include specific farm characteristics, farmer aspirations and skills including to retain pasture quality. By contrast, decreasing stocking rate without improving productivity (i.e. simply down-scaling sheep & beef operations) results in significant reductions in profitability, with implied carbon costs of mitigation ranging from \$60 to more than \$200/tCO_2e.
- Replacing breeding beef cows on hill country farms with systems that finish surplus animals from the dairy herd (bulls and steers) would have minor benefits in terms of emissions reductions (1-4%) but lift profitability of our model farms by more than 50%. However, finishing stock (especially bulls) require different farm management practices, including infrastructure improvements (which were not included in our study). Such systems also require increased farmer skill and can provide challenges for maintaining pasture quality. These barriers provide some explanation why this approach is not adopted more widely.
- Other measures, such as changing the sheep/cattle or male/female ratio, or removing nitrogen fertiliser inputs, generally result in minor to negligible emission reductions. Implications for profitability can be significant but positive or negative depending on the specific farm system, making it difficult to reach robust general conclusions regarding mitigation costs.
- Some mitigation options such as forestry are highly sensitive to commodity prices; when meat and wool schedules are low, introducing forestry and reducing stocking rates while improving productivity become relatively more attractive. Shifting beef production towards finishing surplus animals from the dairy herd appears less sensitive to payment schedules.

For deer farms:

- For deer systems, we do not have a detailed animal or farm system model, making conclusions more conjectural and constraining the range of mitigation scenarios that can be explored. Reducing stocking rates in general appears to offer emission reductions of around 10% and could result in minor increase in profitability. Increasing forestry can reduce net emissions significantly but appears more costly than for sheep & beef systems, even if this approach is limited to marginal land only.

For horticulture and arable cropping:

- GHG emissions from horticulture and arable systems constitute only a minor fraction (less than 3%) of New Zealand’s total biological emissions. In addition, on-farm emissions tend to have a much higher fraction of total GHG emissions from the use of energy and fossil fuels, and this is the area where the most significant mitigation options could be implemented. Approaches to reduce biological GHG emissions (predominantly N_2O) arise from more efficient use of fertilisers and irrigation, and efforts to increase soil carbon storage[2].

Change from livestock systems towards lower-emitting land uses (other than forestry):

- Our results indicate that currently, deep emission reductions from agriculture rely on land-use change away from dairy and sheep & beef sectors towards activities with significantly lower GHG emissions per hectare. While forestry offers the benefit of carbon sequestration and hence greater emission reductions, its low profitability means it is not a realistic prospect to reduce on-farm GHG emissions from the dairy sector. By contrast, horticulture in principle can offer much higher profitability at relatively low GHG emissions per hectare. In principle, land-use change from livestock towards horticulture could therefore help diversify some farm systems while retaining overall profitability, even if emissions reductions would be more limited and depend on the specific type of enterprise.
- A preliminary assessment suggests that a large area of land currently in livestock production (1.5 million hectares) would in principle be suitable for horticulture. However, dairy farming remains the dominant land use despite apparent higher profitability of horticulture. This indicates the presence of significant barriers to change from livestock towards non-livestock enterprises that a simple comparison of profitability of established enterprises cannot capture. Our study has not explored those barriers in detail, but they would include infrastructure and capital investment costs, the need for regional supply chains, and fragmentation of suitable land. These barriers would require regionally coordinated approaches to ensure the right expertise and management skills are brought to bear. Addressing these issues requires much more detailed analysis before a realistic understanding can be developed of the potential for land-use change to contribute to mitigation goals in New Zealand’s agriculture sector.

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[2] Changes in soil carbon are currently accounted for only when land-use changes (i.e. from pasture to cropping or the reverse), but not when land-management practices change within a given land-use (i.e. adoption of no-till approaches within a cropping system). However, changes in soil carbon arising from land-management practices could be accounted for in future and are therefore included in this report where they appear particularly relevant.

1. Purpose and Context of this Report

1.1 Purpose

The Biological Emissions Reference Group has been established jointly by the New Zealand Government and industry to collaboratively build a robust and agreed evidence base on the opportunities available now and in the future to reduce biological greenhouse gas emissions (methane and nitrous oxide) in New Zealand's primary industries, and what the costs, benefits, and barriers to doing so are.

In support of this purpose, the BERG commissioned the NZAGRC to produce a report on currently available options to reduce biological greenhouse gas emissions (GHGs) from agriculture in New Zealand. The guidelines for this report are briefly that emissions reduction options considered should not be limited to those that also maintain or even increase total production, but can include options that would reduce total production and, in some cases, imply a shift towards alternative land-uses. The report should quantify changes in absolute emission of biological GHGs (methane, CH_4, and nitrous oxide, N_2O), emissions intensity (absolute emissions per unit of product, i.e. per kg of milk solids or per kg of meat), cost and also take into account other environmental concerns such as nitrate leaching and water quality.

This report responds to this request by evaluating a range of farm-scale mitigation options for the livestock, arable and horticultural sectors, including the potential for land-use change to contribute to mitigation objectives. Emissions reductions and their economic implications at farm scale are quantified for the dairy and sheep & beef sectors, which constitute about 97% of New Zealand's biological GHG emissions. Our approach uses model farms representing regionally average farm systems and includes on-farm fertiliser use. For the deer sector, emissions reduction options and their economic implications are quantified only coarsely due to the absence of relevant data and process models. For the horticulture and arable sectors, mitigation options for on-farm emissions are summarised only qualitatively, noting their minor contribution to biological GHG emissions in New Zealand. Their major contribution to mitigation efforts could lie in their potential to support a shift towards land use with lower emissions per hectare in some regions and locations.

This report does not attempt to scale the different on-farm mitigation options and their costs from farm to regional and national scales. The systemic and national-scale economic, environmental and social effects of more widespread adoption of any of the mitigation options presented in this report, as well as implications for New Zealand's position in international markets, would need to be considered carefully but were outside the scope and timeframe for this report.

1.2 Context

Almost half of New Zealand's gross carbon dioxide equivalent (CO_2e) GHG emissions come in the form of CH_4 and N_2O from agriculture, predominantly from ruminant livestock (cattle and sheep). This large share of agriculture emissions presents particular challenges to New Zealand in seeking significant economy-wide reductions of its GHG emissions. Additional emissions associated with agriculture arise in the form of carbon dioxide (CO_2) emissions associated with on-farm operations (energy consumption for transport, storage and processing), and various GHG emissions associated with the production of supplementary feeds and fertilisers imported from overseas. These latter emissions are not included in New Zealand's national emissions inventory since this only includes emissions from within its national borders.

On average, if taking a broader lifecycle perspective, CO_2 emissions constitute about 5-15% of the total GHG emissions in the production cycle including processing. Whatever accounting approach is taken, biological GHGs constitute by far the largest share of total GHG emissions associated with New Zealand agriculture (Ledgard et al. 2009; Ledgard and Falconer 2015; Ledgard et al. 2011).

Biological GHG emissions from New Zealand agriculture in 2015 (the latest year for which official data were available by the time this report was completed) have grown by 16% since 1990. By comparison, the energy sector (New Zealand's second largest source comprising 40% of gross emissions, including both stationary energy and transport) has grown by 37% over the same period.

New Zealand's nationally determined contribution (NDC) under the Paris Agreement is to reduce emissions by 30% below 2005 levels by 2030; in addition, the Government has gazetted an aspirational long-term goal of reducing emissions to 50% below 1990 levels by 2050. The Government has indicated that such targets would be reached through a mix of domestic reductions in gross emissions, emission removals by forestry sinks, and the use of international flexibility mechanisms, such as the trade in international carbon credits. This report provides options and implications of domestic reductions in on-farm biological GHG emissions to contribute to such economy-wide targets.

1.3 Existing work on mitigation options and scope of this report

Most existing work on mitigation options for New Zealand farm systems has (a) either assumed that New Zealand farmers have no options to reduce emissions apart from reducing their total production and changing land-use (an assumption mostly made in national-scale economic modelling, Stroombergen 2015), or (b) relied on a finite set of interventions based on existing or future technologies that fundamentally don't change current farm systems or constrain total production (Reisinger and Clark 2016). Some studies have demonstrated that changing farm systems could also influence GHG emissions, e.g. through intensification or de-intensification including changes to pasture productivity, stocking rates and greater or lesser utilisation of supplementary feeds (Beukes et al. 2010; Dynes et al. 2011; Smeaton et al. 2011). The extent to which these modified systems change national GHG emissions over any specific period will depend on the time scale and number of farms over which such changes can be achieved.

These different approaches have necessarily resulted in somewhat differing conclusions about the ability to reduce biological GHG emissions from New Zealand farm systems, and the consequences for their total production and profitability.

This report seeks to bring the existing strands of work together by exploring feasible changes in farm systems both from a farm management and technical perspective, and by quantifying the consequences of such changes for absolute GHG emissions as well as profitability. This works makes no a priori assumptions about whether total production or profitability of current farm systems increases or decreases with such interventions, but rather treats changes in production and profitability as outcomes from mitigation interventions. The scope of this work includes a consideration of the potential for land-use change within current farm systems (e.g. setting aside some of the land that is currently under livestock production and converting it to a lower emitting land use, such as horticulture, or actively using it to offset emissions from other parts of the same farm, by converting it into forestry). Some of the mitigation options explored in this report will maintain or even increase current production per hectare, whereas others reduce production but may maintain, increase or decrease profitability.

1.4 Caveats and exclusions

Our study is exploratory in nature. Crucially, our study does not suggest any policies to achieve any mitigation outcome (such as a carbon price, regulation, information, voluntary agreements, or other market signals). Our scenarios simply explore how farms could be run differently to reduce absolute GHG emissions if farmers choose or could be persuaded to do so. We do not make any presumption of how to achieve such a change, or indeed the desirability of such a change from an economic, social or wider environmental perspective. Neither does our report model the *actual* response of farmers to any policy signal such as a carbon price. That is, where our modelling indicates that a certain farm system change could be cost-effective for a given carbon price, imposing such a carbon price would not necessarily incentivise farmers to actually undertake such a mitigation measure. Other options may be more attractive in response to any given policy signal.

The focus of our study is at the farm scale where farmers and farm and land managers make decisions. We used model farms representing regional average farms to test the implications of mitigation interventions on emissions and profitability. This approach obviously cannot capture the diversity of farms within a region. Our study does not explore the implications to the wider economy, rural society or environment if mitigation responses were taken up at larger scales. For example, some options would imply less total milk production or a shift from sheep & beef farming to forestry while others change the demand for imported feedstuffs, imply changes in demand for different classes of livestock or potentially change land use. These could have repercussions for New Zealand in terms of trade and its role in international markets as well as rural employment and social services. We provide brief comment on issues of scale in this report where this appears particularly relevant.

The various mitigation options explored span a range of alternative ways of reducing absolute emissions, but some interventions are mutually exclusive to others (e.g. some involve reducing stocking rates whereas others involve increasing stocking rates). Some may be additive but we have not made any attempt to stack options as time constraints precluded this. In addition, it must be emphasised that the modelling approach adopted is not an optimisation approach (and the economic model used, FARMAX, is not an economic optimisation model) and changing multiple variables simultaneously is better approached using optimisation. Our mitigation options cannot be assembled easily into a marginal abatement cost curve but rather represent multiple entry points to mitigation for New Zealand farms. Compatible combinations of interventions will depend on the broader policy and economic environment that farmers face, including international market prices and expectations.

Our study focuses on mitigation options that are available to New Zealand farmers now, with varying implications for GHG emissions, production, and profitability. These options will change over time, not only through innovation in technologies and practices, but also due to changes in commodity prices that crucially influence profitability and cost-effectiveness of various mitigation options. Our report explores how our results might change with changing commodity prices, but does not undertake a forward look at how mitigation options themselves might change over time. We understand that this will be analysed in a separate report. All practices assessed and discussed in this report are already in use by some individual farmers in New Zealand, and the focus of our study is to assess to what extent such approaches might be useful to reduce emissions for the average farmer.

2. Livestock modelling approach and assumptions

For this report, mitigation options are modelled as hypothetical changes to representative current farm systems that could achieve reductions in absolute biological GHG emissions on-farm. Summaries of results are provided in this main report, with a more detailed quantitative characterisation of the farm systems and interventions presented in Appendix I.

Note that modelling is undertaken for average dairy farms for the Waikato/Bay of Plenty (BOP), Canterbury and Southland (as well as intensive system 5 farms for Waikato/BOP and Canterbury for some scenarios), and average sheep & beef farms representing North Island and South Island hill country and intensive finishing systems. This is the only quantitative modelling that could be completed within the time frame stipulated for this report, but the approach could be extended readily to other regions/systems where farm data are available.

2.1 Overview of modelling tools

In order to calculate the impact of changes in farm systems on GHG emissions a modelling approach using two models was necessary. This involved the use of two complementary modelling tools available in New Zealand, namely FARMAX and OVERSEER®.

FARMAX was used to set up the base case and assess the physical and financial consequences of perturbations to the base farm system. The system characteristics from these scenarios were then fed into OVERSEER® which calculated GHG emissions. The productivity and revenue/costs associated with forestry were estimated outside the two models. Any carbon sinks created from forest plantings were calculated from ETS look-up tables. The basic steps were as follows:

- Development of a feasible farm system
- Calculation of farm production and farm profitability
- Calculation of GHG emissions for that system
- Calculation of the production/profitability of forestry (where appropriate)
- Calculation of carbon sequestration levels (where appropriate).

2.1.1 FARMAX modelling

FARMAX Pro is a computer based farm system and economic simulation model developed to improve the transfer of information about alternative livestock policies to New Zealand pastoral farmers. The model indicates the biological feasibility of a given livestock system and allows users to evaluate the economics of alternative livestock policies. The model platform was developed in 1991 as the Stockpol model, and has since been refined, updated and tested against scientific and empirical data. The model calculates the required feed demand for a modelled livestock system within the constraints of user defined pasture growth rates and animal performance data.

The financial component is driven (by default) by payouts/schedules and regional farm expenditure data published by Dairy NZ and the Beef + Lamb NZ economic survey. These can be readily altered manually to incorporate actual farm financial data if required. These financial data essentially work on a "cash-in/cash-out" basis, although FARMAX does include depreciation and wages of management. It does not include capital values, other than taxation values for livestock, and does not calculate or include capital costs for any farm infrastructural improvements (e.g. constructing a feed pad on a dairy farm).

All scenarios were run in the "long term" mode. This ensures that the model is "balanced" regarding pasture covers, stock reconciliations, animal liveweight gains, and supplements. For example, it prompts the operator to ensure that opening and closing stock numbers equate and changes stock between stock classes as they age. It ensures that the system being modelled is stable and repeatable. In "short term" mode the model only considers what is happening within a single year, and will not necessarily ensure that the system is balanced in the longer term.

The model versions used were: FARMAX Dairy; 7.1.0.21, FARMAX Sheep & Beef & Deer; 7.1.2.23. Some previous modelling undertaken for MPI in 2016 was updated for this study as these used Dairy Version 7.0.0.92, and S&B Version 7.0.11.15. Model versions are indicated for each mitigation option in Appendix I.

2.1.2 OVERSEER® modelling

OVERSEER® allows nutrient budgets to be created for a large range of farm systems in New Zealand, from dairy farms through to arable cropping and some horticultural operations. OVERSEER® was initially designed as a fertiliser/soil fertility model and was developed with a set of key ground rules that are necessary to provide comparable results over time. Over time, it has become an important farm nutrient cycling/use/loss model. OVERSEER® assumes the farm management system is constant, good management is practiced and the information entered into the model is reasonable and accurate. Calculations of GHG emissions were added to the Overseer model in 2003.

OVERSEER® requires information about the farm at two scales: the farm scale and management block scale. At the farm scale the type of information required includes: location, types of enterprise (stock), structures present (feed-pads etc.) and feed supplements imported. Splitting the farm into management blocks is an essential part of correctly setting up the model. Management blocks within a farm system are defined as the sum of areas of the farm that are managed differently (e.g. irrigated, cropped, effluent applied), and have different soil types, topography, fertiliser application rates or soil test values. At the management block scale, the type of information OVERSEER® requires includes: topography, climate conditions, soil type, pasture type, supplements used, fertiliser applied, irrigation applied or effluent management system. The nature of the information required will vary depending on the block type, i.e. pastoral block or crop block.

The key drivers of the greenhouse gas emissions as calculated within OVERSEER® are; stock numbers, stock type, dry matter intake per animal, the nitrogen content of the feed, and the use of nitrogen fertiliser. GHG outputs calculated are kg of CO_2e/hectare, for CH_4, N_2O, and CO_2.

The version of OVERSEER® used in the modelling was 6.2.3. Some previous modelling for MPI in 2016 and updated for this study used version 6.2.0. Model versions are indicated for each mitigation option in Appendix I.

2.1.3 Forestry

FARMAX and OVERSEER® are not able to fully incorporate other land-uses such as forestry into their simulations. As a result, for those mitigation options involving a change in land-use for parts of a farm (e.g. from livestock operations to forestry), farm systems were simulated as for the full farm size but with a reduced area of pastoral land and if necessary changes in feed supply and individual animal performance. The implications of forestry for net farm profitability and carbon sequestration rates were incorporated into net farm results via Excel spreadsheets.

Section 2.4 provides details for forestry and other alternative land-use assumptions in this report.

2.2 Detailed livestock farm modelling approach

The project involved the use of a number of FARMAX models previously developed by AgFirst for the average farm for specific regions of New Zealand. These model farms were generally constructed around the relevant statistics available from Dairy Statistics and Beef + Lamb NZ Economic Survey data, which gave the basic size of the farm, stock numbers, and production parameters for different regions of New Zealand. The farm system within each model was essentially developed via expert opinion sourced from within AgFirst, from Dairy NZ for the dairy models, and other consultants for the sheep & beef models. This included such things as; breeding animal live weights, mating, lambing and calving times, supplementary feed levels, nitrogen fertiliser usage, cropping areas, and pasture production levels. The sheep & beef models were also split into steep/rolling/flat management blocks, using regional averages based on Beef + Lamb NZ data. Fertiliser expressed in kg N / ha use was for the total farm area on the milking platform, or for a limited area of the total farm (as indicated in Table 2 below) for sheep & beef farms.

Note that the use of 'average' farms does not necessarily mean that the results are applicable to the great majority of actual farms in the region. While based on the statistics available, these often had to be modified to ensure that the stock reconciliation balanced, and while the farm system was 'average' according to expert opinion, in practice there are a wide range of systems on farms. Extrapolation of the results therefore needs some caution since average values hide the wide range of outcomes achieved on-farm from systems that, for this type of study, can be broadly categorised under a single heading.

System 5 dairy farms were constructed based on the regional average system 3 farms and applying DairyNZ guidelines for more intensive farm operations.

2.2.1 Model farm systems

The model farm systems used were (see also Tables 1 and 2):

Dairy (Table 1):

- Waikato/Bay of Plenty (average, and system 5)
- Canterbury
- Southland

Sheep & beef (Table 2):

- North Island hill country
- North Island intensive finishing
- South Island hill country
- South Island intensive finishing

Table 1: Base Dairy Model Parameters

	Waikato/BoP	Waikato/BoP System 5	Canterbury	Southland
Effective Area (ha)	123	123	232	213
Cows Wintered	367	491	837	611
Milk solids (MS) Production (kg)	139,432	207,486	333,644	226,080
MS / ha	1,134 kg / ha	1,687 kg / ha	1,438 kg / ha	1,061 kg / ha
MS / cow	380 kg / cow	422 kg / cow	398 kg / cow	370 kg / cow
N Fertiliser (kg N/ha)	114	115	111	95
Crop area	4.8ha maize	7.2ha maize	8ha Fodder Beet	Nil
	Purchased Supplements (t DM)			
PKE	304	529		
Maize Silage	146	520		
Pasture Silage		223	215	176
Barley Grain		53	145	174

Table 2: Base Sheep & Beef Farm Parameters

	NI Hill Country	NI Intensive	SI Hill Country	SI intensive
Effective Area (ha)	511	290	1,496	351
N Fertiliser (ha)		37kgN/ha (on 100 ha)		37kgN/ha (on 10 ha)
Crop area	10 ha Swede/Kale	10 ha Kale	20 ha Swedes	10 ha Fodder beet
Opening mixed-age Ewes	1,933	1,263	3,702	1,885
Opening mixed-age Breeding Cattle	131		319	
Opening fattening cattle		105		
Lambs sold prime	1,840	1,649	1,110	2,452
Steers sold	69	45	173	
Heifers sold	36		91	
Bulls sold		57		
Heifers grazed		50		144

2.2.2 Development of mitigation scenarios in FARMAX and OVERSEER®

The FARMAX and Overseer® models do not directly 'talk' to each other. The usual approach is to model a given farm system model in FARMAX to establish feed requirements and economic performance of the specified farm system, and then model that same system in Overseer® to understand how nutrients are cycled in that farm system and to determine the GHG emissions.

Establishment of the FARMAX model

The first step was to develop the appropriate FARMAX model. Each mitigation scenario was a modification of the "base" FARMAX model for a regional average farm. The farm system and management changes specific to each mitigation scenario (such as changing stocking rates, supplementary feeds, or removing land from pasture production and placing it into forestry) were imposed on the base model. Other adjustments were then made to the modelled farm system (such as changing productivity per animal or the amount of supplementary feed purchased or grown on farm) until a feasible solution was obtained consistent with the goals of the mitigation scenario. For some mitigation scenarios, the goal was to maintain the same total production as the base farm, whereas for others, production was allowed to adjust downwards as a result of other management changes such as reduction of total feed availability or milking regime.

For example, for forestry scenarios, a "forestry" area was established in FARMAX, with zero pasture production. For the dairy models this area was taken from the "non-effluent" area, and for sheep & beef models it was taken from the "steep" area. Other inputs to the model were then adjusted according to the goal required; if production was to be maintained in the dairy models, additional supplementary feed was purchased until milk solids production equated to the base model. For the sheep & beef models, where production was not maintained in the face of an increasing area of forestry, capital stock numbers were proportionally reduced until a feasible solution was obtained.

For the dairy modelling, one scenario involved replacing high nitrogen (i.e. protein) feed with a lower nitrogen feed; e.g. replacing imported pasture silage with barley grain. The substitution was based on providing an equivalent amount of ME to the base case. Table 3 gives an example of this substitution for the Canterbury model where purchased pasture silage was replaced by purchased barley.

Table 3: *Substitution of barley grain for pasture silage*

	Silage	Barley
Quantity fed in base case (t DM)	215	145
MJME/kg DM	11.0	12.5
Crude protein (%)	17.0	11.5
Total MJME from purchased supplements in base case	2,365,000	
Barley (t DM) needed to replace ME supplied by silage		189
Total barley fed in mitigation scenario		334
Total MJME from purchased supplements in mitigation scenario	2,365,000	

Within the FARMAX model this substitution was made; i.e. pasture silage reduced to zero, barley grain increased to 334 Tonnes. Feeding levels per animal within the model were then adjusted accordingly to ensure that the same milk solids production resulted.

Note that within FARMAX, pasture growth is either selected from a database, populated with pasture production data collected in New Zealand, or entered manually. For the purposes of this modelling exercise, representative pasture curves for the regions in question were selected from the database based on expert opinion. FARMAX also contains default ME values for these pasture curves, which again can be manually manipulated, but for the bulk of the modelling (other than in scenarios where ME values were deliberately manipulated down), the default values were used.

Pasture production curves were not altered within FARMAX relative to any change in stocking rate although it is recognised that significant under- or overstocking can influence pasture productivity due to sub-optimal pasture cover. In our scenarios, adjustments were made to ensure pasture covers were close to optimum at critical times of the annual cycle. For example, if a proposed stocking rate was too high and resulted in sub-optimal residuals, then either demand was decreased or feed supply increased until a feasible solution was reached.

Transfer of FARMAX outputs to OVERSEER® and calculation of GHG emissions

The next step was to manually transfer the relevant information (e.g. stock numbers, supplementary feed levels, production levels) into OVERSEER®. A separate OVERSEER® file was developed for each modelled scenario.

The OVERSEER® files were based on regional-level default values as applicable. These included regional rainfall and potential evapotranspiration (PET) levels, soil types at a soil order level, soil drainage characteristics, and soil fertility levels. The management blocks within OVERSEER® corresponded exactly to the management blocks modelled within FARMAX.

OVERSEER® then estimated GHG and nutrient discharges levels. Note that OVERSEER® calculates its own intake levels (and hence pasture grown/consumed, and emissions arising from this) relative to stock numbers, animal type, animal size and production levels using a different approach to that used in FARMAX. For implications of these model differences for the interpretation and robustness of results please see section 2.3.

Combination of FARMAX, OVERSEER® and forestry results via spreadsheet

Following the development of the FARMAX and OVERSEER® files, results were then entered into a spreadsheet, where the addition of the forestry financials and carbon sequestration were included.

The data transferred to the spreadsheet included:

- FARMAX: areas, production levels, and profitability
- OVERSEER®: nitrogen and phosphorus discharge levels (kg/ha), and greenhouse gas emissions; CH_4, N_2O, $C0_2$ (expressed as CO_2 equivalents)
- Forestry: carbon sequestration rates and annuity (see section 2.4)

GHG emissions are reported as CO_2-equivalents, converting the modelled emissions of CH_4 and N_2O using the Global Warming Potential that is currently used in reporting these emissions to the United Nations Framework Convention on Climate Change. The balance between CH_4 and N_2O emissions in the total CO_2-equivalent emissions varies somewhat between different base farms. CH_4 is always the dominant gas, with the N_2O percentage ranging from 23 to 26% of total on-farm biological emissions. Different mitigation options have only a minor effect on this balance, with N_2O constituting 20 to 25% of biological emissions in mitigation scenarios. The relative importance of N_2O either remains the same or reduces in most mitigation scenarios relative to the base farm, either because the mitigation increases productivity which reduces CH_4 and N_2O emissions, or because N_2O emissions are targeted directly (e.g. via low-N feeds). Given the relatively small changes in the CH_4/N_2O balance, total biological GHG emissions are a useful indicator for understanding the mitigation outcome even though different gases are tackled by different interventions.

2.3 Issues arising from coupling FARMAX and OVERSEER®

The use of FARMAX and OVERSEER® in tandem raises a number of issues which need to be taken into account when interpreting the results generated, as assumptions embedded in both models have not been 'harmonised' during their development. It was not within the scope of this report to conduct an exhaustive analysis of all the potential issues involved. However, we have done some preliminary analysis of issues where it can assist with interpreting results presented in this report.

2.3.1 Scenario development

Scenarios were created in FARMAX for each 'base' farm system based upon assumptions around such things as farm size, animal number and performance, dietary mix and pasture growth rates. All scenarios were 'tuned' in order to be biologically feasible. Some potential mitigation scenarios were designed to maintain levels of animal production and dry matter (DMI) relative to the relevant base model, and using the same feed resource, but reduce emissions by reducing the number of animals and/or pastoral land area; others were designed to have different levels of DMI through changed pasture and/or supplement intake and so it is to be anticipated they would generate different GHG emissions. For scenarios that seek to maintain animal DMI, every attempt was made to equalise animal DMI across scenarios but small differences still persisted. These 'unintentional' differences, although small, would be reflected in animal numbers and performance data generated by FARMAX and subsequently used as input to OVERSEER®. Such small and unintended differences between base and mitigation scenarios can be significant where the potential mitigation scenarios produced small mitigation effects and need to be taken into consideration when interpreting the GHG emissions generated.

Perhaps a larger issue when interpreting the results from the mitigation scenarios is that FARMAX always creates what it deems 'biologically feasible' systems. This can mean that multiple changes can occur in the development of a mitigation scenario when the intention is to change a single variable. For example, the introduction of large quantities of fodder beet (a low N and low fibre feed) into a dairy system also means that a fibre source needs to be added (e.g. pasture silage) to ensure a balanced diet. Another example is the dynamic nature of pasture ME concentration which will be affected by changes made to supplementary feed supply and stocking rate. Obtaining these feasible solutions is an iterative exercise and hence is influenced to some extent by the model user as there may be more than one feasible solution. Hence two different model users could arrive at slightly different systems for a given mitigation approach. The dynamic nature of FARMAX is a strength but it does mean that careful interpretation is needed when assessing the outcomes of potential mitigation approaches.

2.3.2 Calculation of dry matter intake

FARMAX and OVERSEER® calculate DMI values for the same farm system using slightly different algorithms. Although the animal modules of FARMAX and OVERSEER® are both based on estimating metabolisable energy (ME) requirements (for maintenance, lactation, growth, pregnancy and activity), they are sourced and calculated differently. For example, requirements for maintenance and pregnancy in FARMAX are largely based on equations from the Australian Standing Committee on Agriculture (SCA 1990) and the Agricultural and Food Research Council (AFRC 1993; equations in Parks 1982) with a few adaptations by Bryant et al. (2008). In OVERSEER® animal requirements for maintenance are largely based on equations from CSIRO (2007) and Nicol and Brookes (2007), and requirements for pregnancy are based on Freer et al. (2006). In addition, dietary neutral detergent fibre (NDF) concentration and consumption can impose limits to intake in FARMAX via a filling effect, affecting potential animal production (Allen 1996). However, the different approaches taken by the two models do in fact share a common base, the algorithms published by the Australian Standing Committee on Agriculture (SCA 1990) (but in the case of FARMAX also based on AFRC (1993) and Bryant et al. (2008)). Modifications to this common base should not result in major differences in DMI estimates. For example, an analysis using a common dataset for dairy cattle by H. Clark 2015 (unpublished) found that the difference in estimated DMI between the Nicol and Brookes (2007) approach and the Australian Standing Committee on Agriculture (SCA 1990) approach was ~3%.

The ME value of feed is an important component of the DMI estimates since it is calculated as total ME requirement divided by diet ME concentration (MJ ME/kg DMI). In FARMAX default ME values for pastures, the dominant feed consumed, were used with these values being associated with the particular pasture growth curves chosen (a user-defined input to the model) and utilisation by livestock. The default values for pasture are modified by FARMAX for each farm system constructed according to the prevailing pasture cover (mass) e.g. with high pasture covers ME concentration is reduced because green/brown/dead ratio in the pasture is changed. The default regional monthly ME values for pasture in OVERSEER® were used and these are influenced by growing conditions and nitrogen fertiliser applications. Given the dynamic nature of pasture ME values in FARMAX and the influence of local conditions and management on ME in OVERSEER® it cannot be guaranteed that the pasture ME values used in the two models are exactly the same. This adds another element of uncertainty surrounding estimation of DMI by the two models. Default ME values were also used for supplementary feeds, although these can also be user-defined in FARMAX. Differences in feed ME for some supplements as used in this study are compared in Table 4.

Table 4. *Default ME values for a range of supplementary feeds in FARMAX and OVERSEER®.*

Feed type	FARMAX (MJ ME/kg DMI)	OVERSEER® (MJ ME/kg DMI)
Maize silage	10.8	10.5
Brassicas - Turnips	12.0	13.0
Brassicas - Kale	11.0	12.5
Brassicas - Forage rape	12.0	12.5
Fodder beet	12.8	Not published
Barley grain	12.5	13.0
Palm kernel	11.0	11.6

Scenarios in which the supplementary feed supply (always a minor component of the diet in this particular modelling exercise) is changed in an effort to reduce total DMI and/or N intake have to be interpreted carefully. The outcome of these manipulations may not have consistent effects on DMI in the different models simply because of differing assumptions around the ME content of both pasture and supplementary feeds. As a consequence, the amount of pasture consumed as modelled in OVERSEER® may differ from that modelled in FARMAX even if the same amounts of supplementary feeds are used as inputs for both models. In the scenarios modelled, the net effect on GHG emissions from such feed substitutions is small in terms of absolute magnitude given the dominance of pasture in all farm systems, but it can influence whether a particular substitution results in (minor) decreases or (minor) increases of net emissions. We address those issues where relevant in the discussion of individual scenarios.

Another issue uncovered in a detailed comparison are substantial differences for some feeds in assumed utilisation rates especially of supplementary feeds. For example, the farm models implemented for this study in FARMAX used a utilisation rate for barley grain of 95%, whereas OVERSEER® runs in our study assumed an average utilisation of 70%. Therefore, if estimates of feed quantities for a farm system derived in FARMAX are transferred directly into OVERSEER® for calculation of GHG emissions, OVERSEER® will compensate for its lower utilisation of supplementary feed by assuming higher consumption of pasture than is assumed in FARMAX. In scenarios where the mitigation is based on introducing supplementary feeds with a higher ME and/or lower N content, the mitigation modelled by OVERSEER® will therefore be less than what would have been achieved with a 95% feed utilisation based on the feed inputs assumed and costed in FARMAX.

In the absence of a full harmonisation between the two models (which was not possible for this study), the amount of GHG emissions reductions modelled in OVERSEER® resulting from a change in feed composition may therefore not be fully consistent with the energy intake, production and economic consequences of that feeding regime modelled in FARMAX. As a consequence, mitigation options reliant on a substantial change in total feed composition that result in differences of only a few percent of total emissions need to be treated with caution.

2.3.3 Stock Reconciliation

Information from FARMAX is manually loaded into OVERSEER®. Besides introducing the possibility of transcription errors, this can also can lead to small differences in the way OVERSEER® creates its livestock reconciliation compared to that created in FARMAX for the same farm model. Preliminary analysis suggests this issue is minor in magnitude and does not need to be taken into account in interpretation of the modelling results.

2.3.4 Calculation of methane and nitrous oxide emissions

OVERSEER® was used to estimate methane (CH_4) and nitrous oxide (N_2O) emissions. Calculations of methane and nitrous oxide emissions in OVERSEER® are highly related to dry matter intake (DMI) for the farm system under consideration.

For methane the emissions per unit DMI in OVERSEER® are slightly differently for cattle, mature and young (<1 year) sheep; emission factors are 21.6, 20.9 and 16.8 g CH_4/kg DMI, respectively. Hence systems with different ratios of sheep to cattle, or young sheep to old sheep, would be expected to have slightly different average methane emissions per unit DMI. However, DMI is by far the dominant influence on magnitude of methane emissions.

For nitrous oxide, DMI and the nitrogen concentration (N%) in the feed are the primary drivers in calculation by OVERSEER® emissions. Use of fertiliser N also influences nitrous oxide emissions. In addition, degree of confinement off-pasture, rainfall and irrigation, and soil water properties can be influential. These latter variables were standardised in comparisons between base models and derived scenarios for this report so are of little consequence here. OVERSEER®'s default values for N% of feed were used in the modelling.

2.3.5 Known issues with OVERSEER® GHG emission estimates

An NZAGRC commissioned report by Kelliher et al. (2015) raised issues around the DMI calculations in OVERSEER® (version 6.2.0) for dairy cows as they were approximately 14% higher than those calculated using the Australian Feeding Standards equations implemented in the New Zealand national GHG inventory. Given that the algorithms used in OVERSEER® are to a large extent based on the Australian Feeding Standards the size of this difference was unexpected and unexplained. A subsequent investigation (de Klein et al. 2017) investigated the reasons for the difference and re-ran the analysis from Kelliher et al (2015). It was reported the OVERSEER® (version 6.2.3) estimates for ME requirements were 10 % higher, largely due to the estimate of the ME requirements for animal movement associated with walking during grazing (ME_{move}). On further investigation, it was revealed that on correction of an equation used in ME_{move}, when using the OVERSEER® development version, the estimated ME requirements were similar. A difference of 10-15 % in assumed ME requirements in turn means that CH_4 estimates for dairy cows will be changed by a similar magnitude. Our results partly confirm this since in the base scenarios for the Waikato and Southland intake estimates from OVERSEER® are 13 and 17% greater than those from FARMAX.

However, the interpretation is clouded by the intake estimates for a Canterbury dairy system being 28% greater in OVERSEER® than in FARMAX, but almost exactly the same for a system 5 dairy system in the Waikato. As the system 5 system for the Waikato is used in a single scenario only, we can infer with some confidence that CH_4 emissions for the majority of the dairy scenarios constructed in this study are being overestimated in the version of OVERSEER® we used. This in itself does not affect the relative GHG impact of introducing mitigation measures since it is a systematic error, but it means that the imputed carbon cost of mitigation is underestimated by about 15%.

An overestimation of intake in dairy cattle will also tend to increase N_2O emissions for dairy cattle. A further consideration is that OVERSEER® has a number of ways it estimates N_2O emissions. Its default approach ('farm specific') for all species seems to give very high values in some situations (de Klein et al. 2017) that are not supported by experimental data, and is being reviewed. The

OVERSEER® 'fixed emission factor' approach most closely resembles the approach taken by the New Zealand national inventory although it has not been updated to completely align with recent changes in the national inventory approach. Differences between these two approaches can be substantial; in the North Island hill country base scenario, N_2O emissions were approximately doubled when using the farm specific approach compared with the fixed emission factor approach.

In all new simulations in this report the fixed emission factor routine was used in OVERSEER®. This report also draws on simulations commissioned previously by MPI (Journeaux et al. 2016) in which the farm specific routines were used. Large differences are confined to North Island sheep & beef simulations and for consistency these have been adjusted downwards such that N_2O emissions are estimated as a fixed percentage of CH_4 emissions to align with those found for the same farm types using the fixed emission factor approach.

2.3.6 Summary of issues and caveats arising

- The dynamic nature of FARMAX and the need to develop biologically feasible solutions via an iterative approach means that the model user has an influence on the model outcomes to some extent. In addition, modified scenarios will often involve multiple changes even when the desire is to change a single variable, as FARMAX always tries to construct a feasible solution. This means that when constructing a mitigation scenario, small changes in animal production (e.g. milk yield per cow or body condition) can occur even though the intention was to hold them constant. These can result in 'unintentional' differences in DMI between the base and mitigation scenarios. Such unintended changes can be relevant especially where the GHG mitigation resulting from the intentional changes is small in magnitude.
- Calculated DMI for a specific farm system will differ for FARMAX and OVERSEER® because of slightly different approaches although the magnitude of these differences should be small (but see below). Small differences between the models induced by the different approaches in themselves generally have little relevance to interpretation of GHG emissions from scenarios compared to base farm systems since these differences are systematic and only OVERSEER® is used in GHG estimations.
- The two models use different ME concentrations for both supplementary feeds and pasture. This can influence DMI in a manner that is not necessarily consistent or predictable since pasture ME values are adjusted dynamically by both models. This can affect results particularly where a mitigation scenario consists of a deliberate change between supplements whose ME values differ between FARMAX and OVERSEER®. Scenarios that manipulate supplementary feed thus have to be interpreted with caution.
- OVERSEER®-calculated DMI is the major variable driving differences in CH_4 and N_2O estimated for the base farm systems and scenarios. Correction of an error in the algorithms in OVERSEER® for the ME requirements associated with movement will reduce the overestimated DMI for dairy systems in the version of OVERSEER® used in this report. This overestimation does not affect comparisons between the base farm case and potential mitigation scenarios but does overestimate emissions reductions achieved by the dairy system mitigation scenarios by roughly 15%. Since the carbon cost of mitigation is calculated as the change in EBIT *divided* by the reduction in emissions, this means that the modelled carbon cost of mitigation *underestimates* the real-world carbon cost by almost 15%.
- OVERSEER® users have a choice of routines for estimating N_2O emissions. The default routine ('farm specific') gives very high values in some situations and has therefore not been used in the scenarios tested in this report. Instead the fixed emission factor routine, which closely resembles the New Zealand national inventory approach, was used for all new scenarios.

2.4 Carbon sequestration and profitability of alternative land-uses

Improvements in productivity and efficiency can reduce emissions from livestock below business-as-usual, particularly when expressed as emissions per unit of product. These are unlikely to result in major reductions in absolute emissions if the current area devoted to livestock remains unchanged and/or the amount of feed harvested per hectare is not reduced. Alternative, lower-emitting land-uses would be necessary if the goal is to substantially reduce emissions not only below business-as-usual but also in absolute terms relative to an historical baseline such as 2005 or 1990.

In this report, we quantify the emissions reductions and economic implications of replacing part of the land that is currently under livestock production with forestry. For *Pinus radiata* plantations, robust growth and profitability data exist. However, radiata is by no means the only nor necessarily the most profitable alternative land use; alternatives range from conservation forests using native tree species to viticulture and horticulture and the growing of novel exotic plants with promise of a high-value product. However, for those alternative land uses, information about their GHG emissions and profitability let alone practical viability in areas currently dominated by grazing livestock is generally a lot sparser and more conjectural.

2.4.1 Carbon sequestration and adjustments to profitability

For the purpose of this report, the following approach was taken:

1) **The carbon sequestration potential and profitability of *Pinus radiata* plantations** was quantified and included in farm-scale modelling. The following two options were quantified:

   a) **The 'safe' carbon sequestration potential**, defined as the minimum amount of carbon left after harvest of the first rotation and subsequent replanting. This was quantified on a regional basis based on ETS look-up tables (MPI 2015) for carbon sequestration in radiata forest and residual carbon in above- and below-ground biomass following harvest (with subsequent linear decay).

   b) **A more ambitious 'full rotation' potential**, based on a forest plantation that is not intended for harvesting. Conservation forests could be established by planting or allowing revegetation of native forests, or planting of radiata forests not intended for harvest (or only selective harvest of trees exceeding a certain diameter). For the purpose of this report, we used the carbon sequestration achieved by a radiata plantation at 28 years as a proxy for the carbon sequestration that can be achieved by conservation forests. In practice, conservation forests of course continue to accumulate carbon well beyond a 28-year time horizon. The 28-year radiata carbon sequestration potentials used in this report (provided by Dowling et al. (2017) in a report commissioned for this study) should therefore only be taken as an indication of the order of magnitude of sequestration that can be achieved over the same time horizon through a conservation forestry approach.

Carbon sequestration rates based on Dowling et al. (2017) are somewhat greater than those in the ETS look-up tables (MPI 2015), as Dowling et al. (2017) assume use of the latest genetic variants of seedlings and an optimal planting and pruning regime. Use of the ETS look-up tables for the safe carbon sequestration potential therefore provides a lower boundary for the purpose of this report, whereas use of the Dowling et al. (2017) data provides a more optimistic assumption of carbon sequestration rates over a full 28-year rotation based on current best commercial forestry practices.

It must be emphasised that both the 'safe carbon' and the 'full rotation' sequestration approaches as used in this report provide a once-only mitigation option for a 28-year rotation cycle. If the safe carbon potential is used, the next forest rotation results in no increase in total carbon storage if the default approach from the ETS look-up tables is used; additional forest areas would need to be planted after 28 years if the mitigation benefit for this approach was to be maintained into the longer term future, which could alter the economics for the remaining pastoral enterprise.

If radiata forest is planted for conservation purposes, sequestration continues after 28 years but at a declining rate. Longer term sequestration potentials will depend on forest management approaches and site specific conditions. Sequestration rates would also vary significantly if other tree species are chosen, or if selective logging is implemented as part of the forest management. The sequestration rates used in this report should therefore be treated as indicative and illustrative only.

2) **Allowing native forests to regenerate** generally results in lower rates of carbon storage but a growth profile that extends to more than a century. The purpose of this report is only to illustrate the importance (or not) of alternative approaches to forestry as an alternative land-use. Therefore, carbon sequestration and profitability of *native* conservation forests as compared to radiata plantations (or very long-rotation radiata plantations as illustrated in Dowling et al. (2017)) was not explored in more detail. For mitigation approaches where forestry is seen to be a potentially viable element of a mitigation strategy, more detailed modelling of specific approaches would need to be undertaken.

3) **Horticulture in principle can offer a high-value alternative land use** compared to livestock farming, with profitability of established enterprises significantly exceeding that of typical dairy farms (Clothier et al. 2017). Despite this significantly greater potential profitability, we can find no evidence that horticulturalists are currently buying established dairy farms in large numbers. The reasons for this are unclear but may include hidden costs, lack of knowledge, infrastructure, expertise and labour availability and risk aversion against developing new regional enterprises. Given the limited information on these barriers, we did not attempt to model the profitability of alternative land-uses other than radiata plantations explicitly. We limit ourselves to providing an indication of the level of profitability these alternative land-uses would need to make them viable where livestock production is purposefully reduced to cut GHG emissions. Details of the national potential for alternative land uses (in particular from kiwifruit, apples and viticulture), their current profitability and barriers to significant expansion, are contained in a separate document commissioned for this study (Clothier et al. 2017) and key issues relevant to this report are discussed in Section 8.

2.4.2 Annuity calculations and assumptions

For integration into an economic analysis of a farm system, the profitability of a forestry operation (net value of logs sold relative to establishment and pruning/management costs) needs to be converted into an annuity, i.e. an equivalent annual return on investment. Such an annual return can be realistic for very large forestry holdings with different age classes but is a more artificial construct for small on-farm plantations. These would face high up-front cash costs for forest planting and pruning, and delayed returns subject to uncertainty of international timber prices.

Estimates of profitability and annuities differ depending on regional and location-specific assumptions, including ease of site access, roading network etc (see Appendix II). In this report, we used annuities derived by Journeaux et al. (2016) as well as those provided by Dowling et al. (2017) which have a more detailed regional differentiation. Annuities based on Journeaux et al. (2016), reflecting expert input from forestry consultants and farm forester experience, are generally considerably lower than those from Dowling et al. (2017). The reasons for the differences were not explored as part of this study, but are likely to include different scale and focus of forest management as a primary commercially motivated enterprise or the use of forestry only as part of a larger farm operation (see Dowling et al. 2017), as well as assumptions about accessibility of forestry plantations for harvest especially on marginal farm land that may be more remote and more prone to erosion.

Our detailed results (see Sections 4 and 5) show that the forestry annuity is generally not the primary factor determining whether forestry is a cost-effective mitigation strategy. Other factors such as the underlying farm system (especially the proportion of fixed costs in overall outgoings), and whether the 'safe carbon' or full sequestration potential is used are more important. For conservation forests, we used the estimated costs for establishment and minimal pruning of a radiata plantation based on Journeaux et al. (2016). Again, the detailed cost for this forestry establishment is generally not the determining factor for the viability of conservation forestry as a mitigation strategy but the profitability and cost structure of the pastoral enterprise.

Forestry annuities also depend strongly on the assumed discount rate that compares a present-day investment with a future return. Dowling et al. (2017) provide annuities for a commercial discount rate of 8% as well as a discount rate of 5%. This latter value is used frequently in long-term climate change modelling where investments have a high and long-term societal benefit.

None of the profitability calculations in this report consider changes in land-values, establishment costs of infrastructure or supply chains, and any risk premiums. These are potentially important factors but were outside the scope and timeframe of this report. Where regional low-carbon development strategies include alternative land-uses, it would be critical that these elements are incorporated into a more detailed and holistic appraisal of options.

2.4.3 Changes in soil carbon associated with land-use change

Changes in soil carbon arising from the change in land-use from pasture to forest land were taken into account consistent with the information used in New Zealand's National GHG Emissions Inventory. The steady-state carbon stock in grasslands is 105.66 tC/ha, while that of post-1989 forest land is 91.92 tC/ha (Table 6.3.2, MfE 2016).

As a result, converting pasture into forest results in an overall loss of soil carbon of 13.74 tC/ha (50.38 tCO_2/ha). This loss is assumed in the inventory to occur over a period of 20 years, but for the purposes of this report we assumed that the loss occurs over 28 years to align with a radiata rotation period.[3] This translates into an annual emission of 1.8 tCO_2/ha/yr for each year for the first full rotation cycle, which has to be subtracted from the carbon sequestered by growing trees to determine the net climate benefit of a planting a forest on land that was previously in pasture.

The CO_2 emissions due to soil carbon loss of are generally much smaller than the full rotation sequestration potential but they constitute a significant fraction if only the 'safe carbon' sequestration potential from forestry is considered.

Changes in soil carbon within a land-use type (i.e. arising from greater or lesser cropping on a livestock farm) are currently not counted in the New Zealand GHG emissions inventory and resulting soil carbon changes are extremely difficult to quantify reliably. Possible changes in soil carbon within livestock systems are flagged in this report where they might become relevant if a more comprehensive soil carbon accounting approach were to become feasible and adopted in future.

2.5 Accounting for off-farm emissions

In general, our analysis focuses on options to reduce biological GHGs generated on-farm (including emissions from animals grazed off-farm). However, dairy systems in particular also rely to some degree on buying-in additional supplementary feeds that are then used on-farm. The production of these feeds generally is associated with the generation of biological GHG emissions off-farm (as well as CO_2 from the use of fossil fuels and land-use change). Some supplementary feeds are generally produced within New Zealand, while others (particularly PKE) are sourced from overseas.

If farmers reduce their on-farm biological GHG emissions by buying-in more supplementary feeds that are grown elsewhere within New Zealand, it is critical that those off-farm emissions are included to determine whether there is indeed a national-level benefit in terms of GHG emissions reductions. For feeds that are sourced overseas, biological GHG emissions associated with their production do not alter New Zealand's GHG emissions as reported through its national inventory,

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3 The numerical outcome is the same as if emissions occur over 20 years followed by zero emissions once a new steady state of soil carbon has been reached.

and therefore an increase or decrease in their use could be regarded as irrelevant from a national GHG accounting perspective. However, such emissions can be relevant from an environmental integrity perspective (especially if the source country does not have absolute targets to manage those emissions).

These issues are particularly relevant for some of the mitigation options for dairy systems, and more detailed comment on this is provided in Section 4 where appropriate.

2.6 Interpretation of cost estimates of mitigation scenarios

In general, we report economic results in terms of absolute and relative changes in Earnings Before Income and Tax (EBIT) for base farms and mitigation scenarios. EBIT does not include costs or benefits arising from changes in land values or capital investments associated with specific mitigation interventions. These would need to be considered to fully understand implications of specific mitigation interventions for the long-term viability of farm systems implementing these measures but were outside the scope for this report. As noted above, costs and profits from forestry operations are translated into annuities to allow them to be added to pastoral EBIT to calculate annual net farm profitability, but this is somewhat problematic given the significant time lag between investment and cash return for forestry operations.

Costs generally do not include any cost or benefit of a price on GHG emissions. However, we do report the implicit carbon cost of mitigation – this is simply the net change in total farm system EBIT divided by the amount of emission reductions. This can provide a measure of whether a specific mitigation approach would be cost-effective if all GHG emissions were priced at that level; it does not make any assumption whether farmers would actually choose to undertake such measures if biological GHG emissions and carbon sequestration from forestry were in fact priced at such levels.

Note that this concept of cost-effectiveness only refers to whether a specific mitigation intervention is more profitable for farmers than doing nothing (i.e. retaining their base farm) and simply bearing the cost of emissions. It does not consider whether pricing biological GHG emissions is cost-effective at the national scale (i.e. whether the country as a whole is better off applying a price to biological GHG emissions). At the farm scale, applying a price on biological GHG emissions will always result in a net loss of profitability for the farm operation compared to if those emissions are not priced. Mitigation options considered in this report, including those involving forestry, can only reduce the costs resulting from a price on biological GHG emissions but not eliminate those costs.

For carbon sequestered in forests, farmers would generally receive income while carbon is being sequestered but then have to pay for the carbon lost if and when forests are harvested. The price of carbon is almost certain to increase over time if countries deliver on their commitments under the Paris Agreement. However, for this study, we have not accounted for any changes in carbon prices. The implied carbon cost of mitigation reports reflects a uniform carbon price for all emissions and removals of GHGs regardless of when those emissions and removals would occur.

3. Overview of mitigation options for livestock systems

Options to reduce GHG emissions from New Zealand's dominant, pasture-based livestock systems are limited, and necessarily involve either a reduction in the total amount of dry matter consumed by animals, or a change in (more limited) supplementary feeding practices towards feeds that result in lower emissions per kg of dry matter. For the latter, we confined ourselves to feeds with lower nitrogen content, which would reduce N excretion and hence N_2O emissions. We did not include the potential effect of some feeds on the amount of CH_4 per kg of dry matter (such as fodder beet or forage rape), since the evidence base for this, including viability for actual farm systems and net effects including on N_2O emissions, is still limited and considered to be at the pilot rather than farm practice stage.

Based on these considerations, reducing *absolute* GHG emissions based on currently available technologies and practices can be broadly grouped into three broad areas:

1) Improving the productivity/efficiency of farm systems, by increasing the proportion of feed consumed by animals that contributes towards the production of milk and meat, *and* adjusting stocking rates downwards to deliver absolute emissions reductions
2) Reducing the GHG emissions for a given amount of feed, e.g. by replacing high-protein feeds with feeds that have a lower protein (nitrogen) content and hence reduce the amount of nitrous oxide emitted (and nitrogen leached) per unit of feed eaten
3) Reducing the amount of feed eaten by reducing the total livestock production on a farm, accompanied by less feed grown per hectare and/or purchased, and/or turning parts of the farm area towards alternative land uses.

Using these consideration as a generic framework, we developed a set of mitigation interventions whose implications for GHG emissions, production, and profitability at farm scale were modelled in detail. Note that these interventions do not exist in isolation, and actual farms may use a combination (e.g. improving the production efficiency *as well as* utilising feeds with lower nitrogen content *as well as* turning parts of the farm towards alternative land uses). However, the viability of such combined approaches becomes more and more dependent on the individual characteristics of a farm as well as the aspirations of the farmer/land manager. This includes a prioritisation between maximising profitability, effort and labour required, personal goals, and other aspirations for the farm system and its interaction with the surrounding rural community and environment.

Nonetheless it is important to recognise that the interventions we modelled do not represent 'optimised' farm systems, and any real-world farmer would likely seek to make improvements that could increase its profitability relative to the modelled 'single-focus' intervention. On the other hand, the models used in this study make some simplistic and optimising assumptions (including the full availability of farmer knowledge and skilled farm labour supply to suit the demands of the farm), which could mean that in practice the profitability and/or productivity on any given farm would fall below that modelled. The model results for each intervention should therefore best be understood as indicative directions of change, not as predictive forecasts of the precisely quantified result of any intervention implemented in practice for any given farm.

Table 4 below summarises the interventions that were modelled in detail. Some of the interventions reduce GHG emissions while maintaining total production (column 1) through increased efficiency and/or buying-in low-N supplementary feeds, whereas others achieve emissions reductions through a drop in total production (column 2) arising from a range of specific measures. A third set of interventions (column 3) seeks to achieve mitigation through more fundamental farm system changes, including the introduction of significant land-use change towards forestry (and associated changes in the pastoral enterprise), once-a-day milking and other measures (which may or may not reduce total production depending on their implementation). Those mitigation options are not comprehensive, and many more variations would have been possible, but we consider that they span a meaningful range of possible entry points to achieve emissions reductions.

We did not model the widespread introduction of housing and/or stand-off pads in dairy systems. The main reasons for this is that increasing the proportion of animal wastes treated in anaerobic ponds has a minor impact on absolute and emissions and emissions intensity from the farm system as a whole, even when additional CH_4 emissions are 'captured', because emissions of N_2O still arise from spread manure. If CH_4 emissions arising from anaerobic ponds are not fully captured, net emissions could increase rather than decrease from this option under the current national inventory approach. Housing and stand-off pads generally are far more relevant where nitrogen and phosphorous losses or concern for pasture production during wet periods are the primary driver (van der Weerden et al. 2017). In addition, given the high capital investment cost required for stand-off pads and housing, introduction of such management systems is often associated with a further intensification of farm operations that may reduce emissions intensity but increase absolute emissions per farm substantially.

Increased use of urease inhibitors is another mitigation option that was considered but not modelled in detail because of the limited mitigation potential. Urease inhibitors slow the loss of nitrogen from urea-containing fertilisers (the vast majority of N fertilisers used in New Zealand) into ammonia and increase the amount of nitrogen retained in the soil. However, given that this inhibitor tackles only a minor loss route and in the current national inventory calculations is applied only to emissions from nitrogen fertiliser and not from urea deposited directly by animals, the emission reductions that could be achieved are very minor. We undertook an order-of-magnitude estimate using the national inventory tool and found that even if all N fertiliser sold in New Zealand was coated with urease inhibitors[4], this would reduce total N_2O emissions from fertiliser by less than 3.5%. Given that fertiliser makes up only about one fifth of total N_2O emissions, and N_2O makes up less than 30% of total biological on-farm emissions, the full use of urease inhibitors would thus reduce total national biological GHG emissions by no more than 0.2%, which was considered insignificant.

The nitrification inhibitor DCD has not been considered in this study because it was removed from the market in 2011 following the discovery of residues in dairy products. Its re-introduction may be an option in the future, but earlier modelling studies (Reisinger and Clark 2016) have shown that it is a very high-cost option and would result in only minor reductions of total biological emissions at the national scale. The main benefit of DCD would be for water quality in some catchments, with reductions in GHG emissions a co-benefit but unlikely to be the primary motivation for its use.

As noted above (Section 2.4), forestry as modelled in this report provides only a one-off mitigation for a single 28-year period. If a forestry-based mitigation approach were to be continued over a longer time horizon, additional pastoral land would need to be planted in trees after 28 years especially if the approach relies on the 'safe carbon' potential for harvested forests. For conservation forests, sequestration continues beyond the (in that case arbitrary) 28 year time horizon albeit with a declining rate over time.

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[4] In 2015, 16% of all N fertiliser sold in New Zealand was coated with a urease inhibitor.

Table 5: Overview of mitigation interventions modelled for dairy farms

Modelling was carried out for average Waikato/BoP and average Southland model dairy farms, based on DairyNZ data, and additional tests for Waikato and Canterbury system 5 (intensive) model dairy farms and average Northland and Taranaki model dairy farms.

Maintain production/Area farmed	Reduce production	Management &/or Land use change
Lower Stocking Rate (SR) / increase per cow production to maintain total farm production (also run for a system 5 farm)	Lower SR / increase per cow productivity but with partial decline in total production (due to assumed decline in pasture quality October-March for Waikato/BOP farm)	Increase other land-uses (forestry) and increase SR to maintain, or not quite maintain, production
Feed low N supplements grown off-farm	Remove cropping	Intensify to system 5 and increase forestry to offset growth in GHGs per pastoral ha (Canterbury only)
	Remove N fertiliser	Plant trees on marginal land/maintain production
		Feed low-N supplements grown on-farm; reduce pastoral ha
		Once-A-Day (OAD) milking. Variety of implementation options modelled, not all resulting in reduced total production and not all resulting in reduced absolute GHG emissions.

Table 6: Overview of mitigation interventions modelled for sheep & beef farms

Modelling was carried out for average North Island and South Island hill country model sheep & beef farms, based on Beef + Lamb NZ data (and for some options, separately for North and South Island intensive and hill country model farms). Note that due to the heterogeneity of farms, some mitigation options that are not profitable for the average farm may still offer considerable mitigation potential for some individual farms. We provide commentary on this issue where relevant.

Maintain production/Area farmed	Reduce production	Management &/or Land use change
Decrease SR / increase production per animal	Decrease SR, minor increase in production per animal	Increase other land-uses (forestry) and increase stocking rate to (almost) maintain production
	Remove N fertiliser	Plant trees on marginal land only / maintain production
		Replace breeding cows with bought-in beef from the dairy herd
		Alter sheep to cattle ratio
		Increase male/decrease female cattle

4. Quantitative mitigation options for dairy systems

When interpreting the dairy scenarios the issues raised in Section 2.5 about the choice of accounting methodology for off-farm emissions must be born in mind.

The standard approach we have used throughout this report is to estimate biological emissions using OVERSEER®, which accounts only for emissions produced from within the farm boundary. This approach will underestimate emissions in situations where off-farm grown feeds are used. To examine the net benefit to New Zealand of a specific intervention, both the on-farm and the broader off-farm effects need to be considered. For example, greater use of a bought-in feed grown in New Zealand may reduce emissions on-farm but these reductions might be offset to some extent by emissions from growing this feed.

The situation is more complex when considering feeds produced outside New Zealand since emissions from these feeds are accounted for in the country of origin, not New Zealand. For example, if imported PKE is replaced by a New Zealand grown feed such as maize, net emissions from New Zealand would be a balance between the change in on-farm emissions from using this feed and the increase in emissions from growing additional maize within New Zealand. The use of PKE in particular is highly sensitive due to broader social and environmental concerns about its production in source countries. We have indicated in the text where accounting for emissions from PKE would influence the net mitigation outcome, even though under international accounting rules these are not New Zealand's responsibility.

In the following discussion we have specifically addressed the accounting issue where it significantly affects whether an intervention is of net benefit to New Zealand and/or whether it affects the estimated carbon cost of mitigation. This applies particularly to scenarios that replace existing supplementary feeds with low-N feeds, and scenarios that rely on intensification to a system 5 farm (which uses much higher levels of supplementary feeds sourced off-farm).

Note that some other scenarios also have minor changes in the amount of supplementary feeds used, but we have not considered off-farm emissions in those cases where this does not fundamentally alter the conclusions about the scale and economic viability of the mitigation outcome, and would change quantitative results only in a minor way.

Another general issue when modelling farm systems is the actual amount of fertiliser used. The figures used in our model farms are based on DairyNZ data and local consultant expertise, and may be somewhat lower by 10-15% than values assumed in other studies. However, absolute emissions do not depend strongly on the assumed fertiliser use. For example, in the Canterbury system, even if fertiliser use is doubled from 111 to 222 kg N/ha, this increases N leaching by 23% and N_2O emissions by 17%, but total biological emissions (on-farm only, excluding emissions embedded in feed sourced off-farm) increase by only 4.5%. Different assumptions about actual N fertiliser use in base farms based on available datasets (i.e. varying fertiliser use in the base farm by ±10-15%) are thus unlikely to affect base farm total biological emissions by more than 1% and hence would not fundamentally change the mitigation options evaluated in this report.

4.1 Land-use change: forestry

4.1.1 Scenario description

This scenario considers the potential to change land-use, from dairying to a combination of dairying and forestry, to reduce emissions on-farm. Note that we only consider on-farm changes and our scenarios do not consider the potential for farmers to simply purchase emissions offsets from forestry operations elsewhere. We considered four variants to this approach:

(i) The first scenario increased the proportion of forestry (10, 20, 30%) while maintaining milk production per animal and farm. Stock numbers were held constant, which meant, by default, an intensification (increasing stocking rate) of the remainder of the farm. The intent was to investigate the degree of GHG offsetting involved via on-farm forestry, while maintaining milk production from a reduced area by increasing the level of supplement bought into the farm and increasing milk yield per pastoral hectare. Pasture production on the remaining pastoral area was maintained at the same level as the base farm scenario.

(ii) The second scenario involved increasing the proportion of forestry as per (i) (two scenarios: 10, 30%) while accepting a drop in total milk production of half that of the proportion of area in forestry (i.e. if the proportion of farm in forestry = 10%, the drop in production = 5% compared to the base farm). This scenario was motivated by the fact that maintaining overall production in (i) would require stocking rates in excess of 4 cows/ha for the higher forestry proportion, which can be difficult to manage.

(iii) For one farm system (Canterbury), the system was intensified from system 3 to system 5 (by increasing stocking rate and amount of supplements fed), and then a fixed percentage of the farm was planted in forestry. The intent was to investigate the degree to which the forestry would offset the increased GHG emissions from the intensified dairy system, and how the costs (lost revenue from adding forestry to the dairy system) would balance against the increased revenue from intensifying from system 3 to system 5.

(iv) The fourth scenario involved planting forestry only on marginal areas of pasture within the farm. The intent was to see to what degree more moderate and targeted forestry, covering about 3% of the total farm area, would help offset GHG emissions on-farm. The remaining pastoral farm system was intensified slightly to maintain overall milk production levels. Consistent with the assumption of 'marginal' land, we assumed that pasture dry matter per hectare production of the land to be placed into forestry was only two thirds of the average dry matter production per hectare for the farm.

For each option, we explored how results would differ depending on whether the carbon sequestration from forestry was only for 'safe carbon' levels or for the full sequestration potential from conservation forests, and to what extent results depended on the assumed annuity from the forestry operation, given the range of different estimates (see Section 2.4).

Note that scenario (iii) in particular is highly hypothetical. A farmer who decides to intensify the farm from system 3 to system 5 (on the assumption that this would increase profitability at anticipated MS prices) would be extremely unlikely, in the absence of additional incentives, to then want to forgo this increased profitability for the sake of offsetting emission via forestry despite the increased risk and skill requirements associated with a system 5 farm. This scenario in particular should thus be regarded as a theoretical test of economic and environmental outcomes at a regional scale rather than an attractive option for individual farms.

Whether increasing the amount of forestry on dairy farms has co-benefits for water quality depends on whether total production is maintained or allowed to drop. If it is maintained, water quality may not improve and could even deteriorate, given the much higher stocking rate required on the remaining pastoral land implies increased use of bought-in supplementary feeds if total production is to be maintained. If total production is allowed to drop, this could imply a lower rate of N deposition with attendant reductions in N leaching rates.

4.1.2 Results and discussion

Scenario (i): maintain dairy production on reduced pastoral land area

Taking any fraction of dairy land out of dairy production and placing it into radiata forestry would result in a significant reduction in profitability (Table 7a). This result is not surprising of course, given the much lower profitability of forestry operations (typically around $250/ha) compared to dairying (typically in excess of $2,000/ha). Costs of operating a dairy farm do not scale back proportionally if the pastoral land area is reduced due to the presence of fixed costs, especially if total dairy production is maintained by intensifying the operation on the remaining pastoral land. The latter results in increased operational costs for additional supplementary feed to compensate for the reduced pastoral land area, while income from milk solids remains the same. The loss in profitability (EBIT) is therefore significantly greater in scenario (i) than the proportion of land placed into forestry: if 30% of the land is placed into forestry, EBIT drops by 50% and 63% for the Waikato/BOP and Southland models, respectively; at 10% forestry, EBIT would drop by 15% and 26%.

If 30% of the land were placed into forestry but total dairy production maintained, net emissions on-farm would reduce by 12% and 15% for the Waikato/BOP and Southland farms, respectively, if the 'safe carbon' sequestration potential is used and the loss in soil carbon is accounted for (see Section 2.4). These emissions reductions are mostly due to the carbon sequestration from the forestry operation, with a much lesser effect from the intensified pastoral system. Consequently, emissions reductions would be much greater if the full 28-year sequestration potential is used (as a proxy for a conservation forest; see Section 2.4). If 30% of the land is placed into conservation forestry the reductions would be 83% and 71%, compared with the base case for Waikato/BOP and Southland, respectively (including loss of soil carbon). At 10% forestry the emissions reductions would still be about 25%. However, conservation forests cannot offer on-going sequestration in perpetuity and the time horizon for saturation would depend strongly on the species and management regime (which was not considered in this report).

An additional factor to be considered when assessing mitigation potential is that as forestry area is increased, off-farm sourced supplementary feed is increased to maintain total production. With 30% forestry, supplementary feed use is triple that in the base case. If emissions from additional New Zealand-grown supplementary feeds are accounted for (assuming that all feeds other than PKE are grown in New Zealand), 30% forestry (using only the 'safe carbon' sequestration potential) reduces net emissions by only 9% and 7% for Waikato/BOP and Southland, respectively, compared to 12% and 15% if those off-farm emissions are ignored. The relevance of off-farm emissions is much smaller if the full 28-year sequestration potential is assumed, where emissions are reduced by 80% and 61% if off-farm emissions (other than PKE) are accounted for. Including PKE emissions would further reduce the mitigation achieved in Waikato/BOP, to 6% for 'safe carbon' sequestration and 71% for the full 28-year sequestration potential.

The implied carbon cost of mitigation for scenario (i) is very high, regardless of the approach taken to forestry; in excess of \$600/tCO_2e if the 'safe carbon' sequestration potential is assumed, and \$100-150/CO_2e for conservation forestry, even without considering additional emissions from increased supplementary feed use. In both cases, alternative assumptions for the annuity from the forestry operation itself, or the cost of establishing and maintaining a conservation forest, have only a very minor impact on overall profitability and mitigation cost. The net profitability of the farm enterprise as a whole remains dominated by the dairy operation.

Scenario (ii): allow dairy production to drop by half of the amount of land placed into forestry

The picture remains similar under scenario (ii) (which allows dairy production from the remaining pastoral enterprise to drop) with slightly smaller drops in EBIT of 43% and 59% in Waikato/BOP and Southland, respectively, for 30% forestry. Comparison of results for scenarios (i) and (ii) indicates strongly that intensification of the dairy production system to maintain overall production is not economically effective even before considering the management problems it would pose.

Table 7a. *Summary of key results for dairy, land-use change into forestry. Emissions reflect only on-farm emissions; for a discussion of off-farm emissions arising from intensification on the remaining pastoral land, see text. The 'safe carbon' sequestration potential is used with annuities from Journeaux et al. (2016), but for some scenarios results are also provided using the full 28-year sequestration potential (light grey shaded rows). See text for details and additional scenarios.*

	Stocking rate (pastoral area)	Total Milksolids Production	Biological Emissions Total	Net CO_2 change incl. carbon sequestration from forestry		Pastoral net profit	Enterprise net profit	
	Cows/ha	kgMS	kg CO_2 equivalent (on-farm / total)	Absolute emissions (on-farm / total)	Emissions Intensity (on-farm / total)	EBIT ($ pastoral total/yr)	EBIT (pastoral + forestry annuity)	Carbon Cost of mitigation (on-farm / total)
Take land out of production and into forestry; offset production losses wholly or in part through increased SR and increased supplements								
Waikato/BoP								
Base model	3.0	139,432	1,556,688			$283,275	$283,275	
10% Forestry	3.3	139,803	1,567,266	-3%	-3%	$237,467	$241,895	$1,029
10% Forestry, 28-yr seq. pot	3.3	139,803	1,567,266	-26%	-26%	$237,467	$235,696	$116
20% Forestry	3.7	139,773	1,562,715	-6%	-6%	$176,591	$185,447	$1,024
30% Forestry	4.3	139,378	1,521,018	-12%	-12%	$128,428	$141,712	$753
10% Forestry; 5% drop in production	3.3	132,644	1,497,156	-7%	-2%	$235,268	$239,696	$395
(as above, 28-yr seq. pot.)	3.3	132,644	1,497,156	-31%	-27%	$235,268	$233,497	$104
30% Forestry; 15% drop in production	4.3	118,421	1,330,614	-24%	-11%	$148,936	$162,220	$320
Southland								
Base model	2.9	226,080	2,689,338			$389,361	$389,361	
10% Forestry	3.2	226,160	2,662,287	-4%	-5%	$285,609	$289,358	$827
10% Forestry, 28-yr seq. pot	3.2	226,160	2,662,287	-23%	-23%	$285,609	$282,542	$170
20% Forestry	3.6	226,009	2,600,730	-10%	-10%	$196,923	$204,421	$669
30% Forestry	4.1	226,020	2,569,206	-15%	-15%	$131,780	$143,026	$613
10% Forestry; 5% drop in production	3.0	214,982	2,557,704	-8%	-4%	$301,595	$305,344	$372
(as above, 28-yr seq. pot.)	3.0	214,982	2,557,704	-27%	-23%	$301,595	$298,528	$124
30% Forestry; 15% drop in production	3.5	192,035	2,231,388	-28%	-4%	$149,231	$160,477	$309
Take land out of production and into forestry; intensify farm system (system 3 -> system 5) and offset emissions increase								
Canterbury								
Base model	3.6	333,364	3,959,776			$506,927	$506,927	
Intensify to system 5	3.9	412,472	4,375,752	11%	-11%	$616,098	$616,098	Not a mitigation
Place 12% of system 5 land into forestry	3.9	365,907	3,734,728	-6%	-14%	$408,476	$410,716	$428
(as above, 28-yr seq. pot.)	3.9	365,907	3,734,728	-20%	-27%	$408,476	$404,444	$127

Given the dual emission reductions under scenario (ii) from both carbon sequestered by forests and reduced dairy production, 30% conservation forestry would achieve a 96% emission reduction for the Waikato/BOP farm and 84% reduction for the Southland farm. The reduction is 24% and 28%, respectively, if only the 'safe carbon' sequestration potential is assumed (and 24% and 22%, respectively, if off-farm emissions from additional supplements grown in New Zealand are accounted for). The carbon cost of mitigation drops by about half in this approach compared to scenario (i), but still remains high at about \$300/tCO_2e if only the 'safe carbon' sequestration potential is accounted for, and about \$100/tCO_2e if conservation forestry is assumed.

Scenario (iii): intensify dairy operation (Canterbury) and offset increased emissions via forestry

Scenario (iii) explored the question to what extent intensifying the dairy operation in a region where it is generally highly profitable (Canterbury) would then allow the additional revenue to be used to set land aside into forestry to offset the increased emissions. This was explored by placing an arbitrary 12% of the land into forestry.

Placing 12% of the land of the intensified system 5 farm into forestry would reduce on-farm emissions by about 6% below the base farm, if the 'safe carbon' sequestration potential is used. If the full 28-year sequestration potential (used to approximate a conservation forest) is considered, emissions are reduced by 20%. However, off-farm emissions have to be considered when assessing net benefit of such an approach to New Zealand, as opposed to the benefit to a specific farm operation, since intensifying a farm to system 5 implies a much greater quantity of feeds bought into the farm.

Accounting for *all* emissions related to the increased use of supplementary feeds (including PKE) used in scenario (iii) implies that emissions would increase by 7% if the safe carbon sequestration potential is considered, and reduce by 8% if the full 28-year sequestration potential is considered. If emissions associated with PKE are *excluded* (as they occur outside New Zealand's borders) emissions would drop by 5% if the safe carbon sequestration potential is considered and 19% if the full 28-year sequestration potential is considered. These large differences arise because we assumed that most of the additional supplementary feed needed for a system 5 farm would be in the form of PKE.

Economically, our results indicate that retiring 12% of the land of a system 5 farm results in a drop in profitability of about 33%. This is because a system 5 farm has high fixed costs which do not scale down proportionately with reduced milk production from a smaller pastoral land area. This significant drop in EBIT outweighs the increase in profitability from intensification compared to the base farm. The net result is that the intensified system 5 farm with 12% of the land in forestry has about 19% lower profitability than the (non-intensified) base farm without forestry. Whether forests are planted for harvest (and thus attract an annuity) or for conservation purposes has only a minor impact on this overall profitability as it is dominated by the dairy operation.

The carbon cost of mitigation of this approach depends strongly on the approach taken to forestry and whether biological off-farm emissions are accounted for (see above). If only the 'safe carbon' sequestration potential is considered and all off-farm emissions are accounted for then the approach does not actually reduce emissions. If off-farm emissions from PKE are excluded, the carbon cost of mitigation of this approach would be more than \$400/tCO_2e if the 'safe carbon' potential is used, dropping to \$131/tCO_2e if the full 28-year sequestration potential is used.

Scenario (iv): plant forestry on marginal land only

This final scenario considered forests to be planted on marginal land only (for definition and implementation, see above Section 4.1.1). Model results are based on an earlier study and are thus not strictly comparable to scenarios (i) to (iii). These results suggest that planting marginal land in forests would result in only a minor reduction of emissions (0.4-3%) if the safe carbon sequestration potential is considered, but a more significant impact (4-10%) if the conservation potential is used.

As implemented in this model study, marginal forestry plantings would have little impact on net farm profitability for the Northland, Canterbury and Southland model farms, but reduce profitability for the Waikato/BOP and Taranaki model farms by 3-6% (see Table 7b). However, given the generally small changes in profitability we cannot rule out that these results reflect specific ways in which the scenarios were implemented in our model, including possible spurious results arising from the linking between FARMAX and OVERSEER® (see Section 2.3) rather than a systematic feature of those average regional farm systems.

The impact of removing the 'marginal' land from the dairying platform also would be strongly related to the assumption made regarding the relative pasture production potential of the marginal land (two thirds in this case) used for forestry versus that of the rest of the farm.

The carbon cost of mitigation from marginal forestry plantings is strongly dependent on the modelled change in profitability: high carbon costs (in excess of \$300/tCO_2e) for Waikato/BOP and Taranaki farms if the 'safe carbon' sequestration potential is used and \$77-\$130/tCO2e if the full 28-year sequestration potential is used, moderate carbon costs for Northland (\$13-\$19/tCO_2e) and negative costs (i.e. benefits) for the South Island regions. However, we again stress that those results may reflect the specific way the scenarios were implemented rather than a robust feature of those regional farm systems.

Table 7b. *Summary of key results for dairy, land-use change into forestry (marginal land only). Results are given for both the 'safe carbon' sequestration potential and the full 28-year sequestration potential (light grey shaded rows). See text for details.*

	Stocking rate (pastoral area)	Total Milksolids Production	Biological Emissions Total	Net CO_2 change incl. carbon sequestration from forestry		Pastoral net profit	Enterprise net profit	
	Cows/ha	kgMS	kg CO_2 equivalent	Absolute emissions	Emissions Intensity	EBIT (\$ pastoral total/yr)	EBIT (pastoral + forestry annuity)	Carbon Cost of Mitigation (\$/t)
Plant marginal land into forestry								
Northland								
Base model	2.3	98,462	1,267,245			\$132,435	\$132,435	
4 ha forestry	2.4	98,512	1,267,920	-1%	-1%	\$131,358	\$132,078	\$19
28-yr seq. pot.				-10%	-10%		\$130,782	\$13
Waikato/BoP								
Base model	3.0	139,432	1,647,093			\$311,436	\$311,436	
3 ha forestry	3.1	138,057	1,606,920	-3%	-2%	\$293,328	\$294,408	\$322
28-yr seq. pot.				-9%	-8%		\$292,896	\$130
Taranaki								
Base model	2.9	115,699	1,315,020			\$269,115	\$269,115	
3 ha forestry	3.0	113,312	1,316,175	-1%	1%	\$260,784	\$261,189	\$497
28-yr seq. pot.				-9%	-7%		\$260,352	\$77
Canterbury								
Base model	3.6	333,781	3,787,632			\$586,496	\$586,496	
7 ha forestry	3.7	333,063	3,789,720	-0%	0%	\$593,078	\$593,645	-\$432
28-yr seq. pot.				-4%	-4%		\$592,070	-\$34
Southland								
Base model	2.9	225,899	2,661,435			\$348,681	\$348,681	
6 ha forestry	3.0	225,847	2,662,713	-1%	-1%	\$355,059	\$356,115	-\$295
28-yr seq. pot.				-6%	-6%		\$354,195	-\$33

Summary and broader implications for land-use change

Our results show that regardless of how forestry is implemented, offsetting biological GHG emissions from dairy operations through carbon sequestration on-farm is generally costly, often with high implied carbon costs of mitigation in excess of \$100/tCO_2e. The exceptions to this is forest plantings on marginal land, especially if those forests are planted for conservation purposes. The economics of this will be highly dependent on individual farm characteristics.

Scenario (iii) shows that intensification combined with forestry would still result in a significant reduction in profitability and carbon costs of mitigation in excess of \$100/tCO_2e depending on how biological off-farm emissions are treated. However, this scenario is highly hypothetical since it is difficult to conceive of an incentive structure for farmers encouraging them to expose themselves to the higher risks and skill needs associated with a more intensive dairy operation, and then to forgo the economic benefits of this intensification through setting land aside for forestry.

In general, these mitigation approaches appear more feasible under high milk payouts than under low payouts, simply because the cost of mitigation becomes a smaller fraction of the overall profit in the former case. For example, for the Waikato/BOP farm, if 10% of the land is placed into forestry and total dairy production is maintained, EBIT drops by a fixed amount regardless of the payout since input costs remain fixed. This means that EBIT drops by 15% at a payout of \$5.80/kg MS, 7% at a payout of \$8.00/kg MS, but 125% at a payout of \$4.00/kg MS (i.e. it would turn the farm from a moderately profitable into a loss-making enterprise). However, they all reduce profitability and, since future pay-outs are uncertain, the level of financial risk is markedly increased.

Apart from the economic implications, setting land aside for forestry generally also reduces flexibility in farm operations and thus increases the risk profile for farmers. The opportunity cost of this reduced flexibility has not been quantified in our study but is likely to act as a significant barrier to adoption even if carbon prices were high enough to make it cost-effective for farmers in principle. As a result, if the purpose of forestry is merely to offset emissions, perhaps farmers pooling their emissions and purchasing dedicated (non-dairy) land to generate carbon offsets in New Zealand or offshore would be an economically far more attractive avenue to explore. Another option would be for farmers to purchase dairy support blocks with lower productivity where setting land aside for forestry is more feasible than on prime dairy land.

Some of the scenarios considered here would have co-benefits for water quality. This applies in particular to scenario (ii), where the total dairy production is reduced, but also to scenario (iv), where the N loss to water is lower by about 10% from the system 5 farm that has 12% of the land in forestry, compared to the base farm. However, there may still be practical management issues to achieve those outcomes, given the higher system intensity on the pastoral land area.

As noted in Section 2.4, forestry is not the only alternative land-use that could lower emissions. Our modelling indicates that if in scenario (ii) forestry were to be replaced with another land-use that neither generates nor sequesters GHGs, the profitability of this alternative land-use would have to be in the order of \$4,000 to \$8,000/ha to maintain the profitability of the combined farm operation. Established horticultural enterprises routinely exceed such a profitability, but integrating them at small scale into dairy farms while maintaining profitability poses significant challenges (see also Section 8). Nonetheless, if a strategic and long-term reduction in GHG emissions from dairying is required, identifying and enabling a change towards high-value/low emission land-uses is a possible route for achieving this. However, identifying viable propositions and identifying the barriers to making such a transition would require much more detailed and region-specific analysis than we have been able to undertake in this study (see also the more detailed report by Clothier et al. 2017).

4.2 Reduce stocking rate / increase productivity

4.2.1 Scenario description

This scenario explores the extent to which higher productivity per cow combined with lower stocking rates can reduce GHG emissions. The main reason why such an approach is a mitigation measure is that more productive cows use a greater proportion of the feed they consume to produce milk rather than to maintain their daily activities. If cow numbers are dropped at the same time as productivity per cow is increased, this in principle can allow the maintenance of overall farm milk production but with lower amounts of feed consumed and thus lower GHG emissions.

Reducing stocking rates in principle could affect pasture production, quality and utilisation, depending on management. However, as this scenario reduces stocking rates by no more than 15% compared to the base farm and the assumed increased feed intake per cow is well within observed outcomes, we maintained default pasture production and utilisation rates from FARMAX. However, we explored the sensitivity to changes in pasture quality by constructing a specific scenario in which reducing the stocking rate resulted in a reduction in feed quality.

Several variations to the generic approach were modelled:

(i) In the first mitigation scenario, we reduced stocking rates (by 5, 10, 15%) while increasing productivity per cow by the same degree to maintain overall total production. The increase in milk production per cow was achieved using less supplementary feed relative to the base, due to the lower stocking rate making more pasture available per cow.

(ii) Recognising that maintaining pasture quality during summer can be a challenge at lower stocking rates, we explored a variation to scenario (i) where the pasture ME values in FARMAX were reduced by 0.2 MJME/kg DM over the period October to March. This scenario was only modelled for the average Waikato/BOP farm as this would experience greater challenges in maintaining pasture quality during summer than irrigated Canterbury farms or cooler less drought prone Southland farms.

(iii) Both scenarios (i) and (ii) (reducing stocking rate at the same or with a slight decline in summer pasture quality) were also modelled for the average Waikato/BOP System 5 farm.

This mitigation approach should also present moderate co-benefits to water quality through the reduction in total feed consumption. Note that shortfalls in pasture quality (as modelled in scenario (ii)) could in principle also be compensated for by increasing supplementary feeds, but this would increase operating costs. Such additional variants on scenario (ii) were not modelled explicitly.

4.2.2 Results and discussion

Our modelling results suggest that reducing stocking rates and proportionally increasing per animal productivity offers relatively modest reductions in absolute emissions (3-9% for a reduction in stocking rates of 5-15% percent). Importantly they also increase profitability compared to the base farm system (up to 15-16% if stocking rate is reduced by 15%). Details are summarised in Table 8.

The direction of change is consistent across the different stocking rate/production per cow assumptions used in this study. It is found also for the Waikato/BOP system 5 farm (with an even greater increase in profitability), and persists if pasture quality is assumed to drop by 0.2 MJME/kg DM for the October to March period. However, in this latter case it reduces the increase in profitability from 15% to 12% at a reduction in stocking rate of 15%, and removes the increase in profitability entirely if the stocking rate is reduced by only 5%.

In the Waikato/BOP, implementing this option (at the maximum reduction of stocking rate of 15%) would reduce N loss to water by about 9%, and in Southland by about 5%.

The implication of these results is that for the average dairy farm in both the Waikato/BOP and Southland their environmental *and* economic performance could be lifted by giving greater emphasis to increasing productivity per animal while reducing stock numbers. This is consistent with first principles. While details of the model set-up (see Section 2.3) can affect the quantification of this mitigation approach they are unlikely to change the overall picture for this option.

There are significant caveats to this conclusion. One general observation is of course that despite its economic and environmental attractiveness (even in the absence of any climate policy), a reduction in stocking rates and increased focus on per animal production is not currently being implemented as widely as the modelling results suggest it could be. Our study has not been able to explore the reasons for this in detail, but a clear element is that this approach requires enhanced farmer skill (including investments in pasture monitoring and management, which are not costed in our modelling approach) and exposes farmers to greater risk of losing pasture control. Managing this risk, including through topping and conservation, would increase costs and requires additional skill. At the same time, reduced stocking rates help reduce and manage some other risks, including those arising from summer/autumn droughts or wet weather during the calving period. A related challenge is to maximise the daily intake for each animal based on the available pasture under the lower stocking rate, to achieve the increased productivity. This adds to the skill challenges for farmers along with the need to maintain pasture quality.

As previously noted in Section 2.2, we have used the default FARMAX setting that the total amount of pasture produced would not decline with the reductions in stocking rates considered in our scenarios. If in practice a reduction in stocking rate results in a decrease in pasture production the economics of this mitigation approach would change. Similarly, a reduction in pasture quality greater than the 0.2 MJME/kg DM considered in our model could change this approach from economically profitable to non-profitable. Farmers would have the option of increasing supplementary feeds to make up for any reduction in pasture quality and yield, but this would present additional costs. Undertaking a reduction in stocking rates and increasing milk yield per cow thus expose farmers to a different risk profile. The economic risk is not one-sided, as high stocking rates also expose farmers to risks when milk payouts drop sharply or during severe droughts, as this either increases costs to maintain feed or increases losses from having to sell stock at low prices. FARMAX does not consider risk premiums in determining profitability, but risk is a well-known reason for why apparently cost-effective measures remain under-implemented (Jaffe 2017).

The approach of lowering stocking rates and increasing production per animal is relatively more attractive at low milk payouts than at high payouts, because the approach as modelled reduces input costs by a fixed amount. Thus, the relative gain from this approach is greatest when revenue is low (e.g. for the average Waikato/BOP farm, reducing stocking rate by 15% lifts EBIT by 15% at a milk price of $5.80/kg milk solids, but by 6% and 135% at prices of $8.00 and $4.00/kg milk solids, respectively). Hence the farmer appetite for this type of intervention will be strongly dependent on expectations about future milk payouts, and historically high payouts made this approach much less attractive than it would be if milk prices remain below about $6/kg milk solids.

The dependence on the milk price is even stronger for the Waikato/BOP system 5 farm especially when a potential drop in summer pasture quality is taken into account. This is due to the relatively higher fixed input costs and hence greater penalty for any drop in total milk production resulting from lower pasture quality.

__Table 8.__ Summary of key results for dairy, reducing stocking rate and increasing productivity per cow.

	Stocking rate (pastoral area)	Total Milksolids Production	Biological Emissions Total	Net CO_2 change		Pastoral net profit	
	Cows/ha	kgMS	kg CO_2 equivalent	Absolute emissions	Emissions Intensity	EBIT ($ pastoral total/yr)	Carbon Cost of Mitigation ($/t)
Reduce stocking rate/maintain production							
Waikato/BoP							
Base model	3.0	139,432	1,556,688			$283,275	
Less 5%	2.8	139,370	1,509,825	-3%	-3%	$299,298	-$342
Less 10%	2.7	138,977	1,460,748	-6%	-6%	$315,437	-$335
Less 15%	2.5	137,280	1,408,842	-9%	-8%	$326,891	-$295
Southland							
Base model	2.9	226,080	2,689,338			$402,117	
Less 5%	2.7	226,080	2,607,120	-3%	-3%	$399,522	$32
Less 10%	2.6	226,148	2,531,931	-6%	-6%	$444,996	-$272
Less 15%	2.4	226,140	2,448,648	-9%	-9%	$465,848	-$265
Reduce stocking rate/Reduce ME by 0.2MJME/kgDM from October to March							
Waikato/BoP							
Base model	3.0	139,432	1,556,688			$283,275	
Less 5%	2.8	136,151	1,502,937	-3%	-1%	$282,129	$21
Less 10%	2.7	135,813	1,448,202	-7%	-4%	$298,341	-$139
Less 15%	2.5	135,253	1,400,355	-10%	-7%	$316,730	-$214
Reduce stocking rate/maintain production on system 5 farm							
Waikato/BoP							
Base model	4.0	207,486	2,162,832			$216,484	
Reduce SR by 10%	3.6	207,208	2,034,666	-6%	-6%	$274,431	-$452
Reduce SR by 10%, red. summer ME	3.6	203,766	2,014,863	-7%	-5%	$258,441	-$284

Some farmers have been moving in this direction, motivated perhaps in part by recent low payouts and a more muted longer term forecast of milk prices. Implications of a more widespread and consistent adoption of this approach for profitability in the real world are difficult to ascertain because in many cases, farms that have implemented lower stocking rates also sought to more aggressively reduce nitrogen inputs than in our hypothetical scenario. Concurrent changes in milk payouts and other changes in the farm system further complicate any direct comparison of real-world farm data with this modelled scenario. However, we consider that the available experiences from P21 trials and e.g. the Lincoln University Dairy Farm indicate that the approach is indeed feasible even if economic outcomes will not always match the modelled results because of multiple concurrent changes in real-world farm systems.

However, improved understanding of farmer and industry attitudes and of barriers to a more systematic adoption would be necessary to more fully understand the scale at which this apparent no-cost mitigation option could be implemented across the dairy industry. The increased use of high breeding-worth (BW) animals would be one way to help farmers implement lower stocking rate and increased productivity systems with lower risk of losing pasture quality, and to reduce the risk that cows increase their production by losing body condition rather than by increasing their pasture intake.

4.3 Low-N supplementary feeds

4.3.1 Scenario description

These scenarios explore the extent to which the increased use of low-N supplementary feeds could help reduce overall emissions by reducing the overall N content of the animals' diet and thus reducing overall N deposition and N_2O emissions. The increased use of low-N supplements could either replace supplements with a higher N content (e.g. replacing Palm Kernel Expeller with maize silage, or pasture silage with barley grain), or substitute pasture with low-N supplements (e.g. increase the amount of maize silage or fodder beet grown on-farm at the expense of pasture production).

Scenarios were run for the Waikato/BOP farm model, where the main switch was from PKE to maize silage (either bought-in or grown on-farm), and the Canterbury farm model, where the main switch was either from pasture silage to bought-in barley grain, or from pasture silage and barley grain to on-farm fodder beet. Maize silage has lower N content than PKE, barley grain has lower N content than pasture silage, and fodder beet has lower N content than both pasture silage and barley grain; as a result, all of these switches should lower the overall N content of the diet and hence reduce N_2O emissions.

In determining the amounts of low-N supplements required, we considered the ME of pasture and supplements such that total energy intake and hence production in the farm system remained the same, with the only net difference being the level of protein in the total ration. Where the low-N supplement has a lower ME than the original feed ration (e.g. maize silage replacing PKE), this can increase intake required to maintain production and thus increase CH_4 emissions, which partially offsets reduced N_2O emissions. On the other hand, if a low-N supplement has a higher ME than the original feed ration, this approach can result in reductions of both CH_4 (via reduced intake) as well as N_2O (due to lower N excretion).

As FARMAX and OVERSEER® do not have a common ME and protein characterisation for feeds nor a consistent utilisation rate (see Section 2.3), the magnitude of changes in both DMI and N intake will not necessarily be entirely consistent. However, the same basic principles apply to both models; substitution of a high N feed with a lower N feed lowers N intake although this can be offset to some extent if the lower N feed has a lower ME than the feed it replaces as this will result in a higher DMI overall.

A lower N content in the overall diet will generally have a positive effect on N leaching and hence water quality, although the magnitude of the effect may be small, depending on the fraction of total feed consumed as supplementary feed.

4.3.2 Results and discussion

Our results indicate that switching to low-N supplementary feeds can result in minor (1-2%) to potentially significant (>10%) emission reductions; results depend on the regional base farm system, implementation via bought-in or on-farm supplements, and changes in biological off-farm emissions associated with the production of the supplementary feeds. For details, see Table 9.

Waikato/BOP farm model

For the Waikato/BOP farm model, replacing all supplements with bought-in maize silage results in two competing effects. The ME content of maize silage is lower than that of PKE, so total dry matter intake has to increase slightly for total production to be maintained.[5] As CH_4 emissions correlate

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[5] The difference in ME between maize silage and PKE is marginal in FARMAX (10.8 vs 11.0) but greater in OVERSEER® (10.5 vs 11.6), but FARMAX has a substantially higher utilisation for PKE (90%) than OVERSEER® (70%), resulting in some inconsistencies between the two models. The net change in DMI in this scenario is thus to some degree a result

strongly with dry matter intake, these changes result in an increase of CH_4 emissions by 2.5%. On the other hand, the nitrogen content of maize silage is lower than that of PKE or pasture, which results in a reduction of N_2O emissions of 2.8% despite the increased dry matter intake. The net effect of those changes is that on-farm emissions increase by 1%, because CH_4 constitutes about three quarters of total on-farm biological emissions.

Whether these changes result in a net reduction of absolute emissions for New Zealand also depends on how off-farm emissions are accounted for, as maize silage produced off-farm still results in biological GHG emissions within New Zealand, mainly from the use of fertiliser. If only those off-farm emissions likely to occur within New Zealand are counted, emissions would actually *increase* by 3% because of the need to produce more maize silage off-farm. If *all* biological off-farm emissions are taken into account (including those from PKE occurring off-shore), buying-in maize as alternative supplement reduces total emissions by 6% below the base farm emissions as the relatively high emissions from the use of PKE in the base farm are avoided.

The overall effect on emissions is somewhat more consistent if all maize silage is grown on-farm to replace PKE and bought-in maize silage. Achieving this would require an additional 30.2 ha out of the 123 ha model farm to be planted in maize. In this case, biological on-farm emissions would decline by 4%. If off-farm emissions likely to occur within New Zealand are considered, the net emission reductions are 5%. If *all* biological off-farm emissions including those from PKE are considered, net emission reductions are as large as 13%.

Table 9. *Summary of key results for dairy, increase utilisation of low-N feeds. Results are provided for both for on-farm emissions only, and including off-farm emissions likely to occur within New Zealand (i.e. all off-farm emissions excluding those associated with PKE) (light grey shaded rows). For details, see text.*

	Stocking rate (pastoral area)	Total Milksolids Production	Biological Emissions Total	Net CO_2 change		Pastoral net profit	
	Cows/ha	kgMS	kg CO_2 equivalent	Absolute emissions	Emissions Intensity	EBIT ($ pastoral total/yr)	Carbon Cost of Mitigation ($/t)
Feed low-N supplements							
Waikato/BoP							
Base model	3.0	139,432	1,556,688			$283,275	
(incl. off-farm emis.)			1,715,368				
Buy in maize silage	3.0	139,259	1,576,491	-6%	+3%	$268,263	$158
(incl. off-farm emis.)			1,620,191	+3%	-5%		Not a mitigation
Grow all maize on-farm	4.2	139,244	1,494,450	-13%	-5%	$281,935	$6
(incl. off-farm emis.)			1,495,499	-5%	-13%		$18
Canterbury							
Base model	3.5	333,664	3,959,776			$506,927	
(incl. off-farm emis.)			4,001,912				
Buy in barley grain	3.5	333,892	3,774,408	-5%	-5%	$488,180	$101
(incl. off-farm emis.)			3,828,826	-4%	-4%		$108
Grow fodder beet on-farm (maintain MS prod.)	4.0	333,753	3,907,808	-1%	-1%	$567,996	-$1,175
(incl. off-farm emis.)			3,916,111	-2%	-2%		-$712
Grow fodder beet on-farm (reduce MS prod.)	3.8	314,669	3,867,440	-2%	4%	$499,801	$77
(incl. off-farm emis.)			3,875,743	-3%	3%		$56

of the FARMAX/OVERSEER® model interaction. The amount by which CH_4 emissions are modelled to increase may therefore to some extent be an 'unintended' consequence of the model setup (see Section 2.3).

Economically, buying-in all supplements in the form of maize causes farm profitability to drop by 5%, with a high implied carbon cost of mitigation well in excess of \$100/tCO_2e. By contrast, growing all maize on-farm has a negligible impact on profitability. This suggests that expanding the on-farm maize component of supplementary feed could offer a modest but essentially no-cost on-farm emission reduction. The reduction is greater if off-shore emissions embedded in PKE are included.

These conclusions come with significant caveats. The main one is that if this approach were taken up at scale, it would require a significant amount of additional land to be placed in maize production. Cropland has a lower soil carbon content than pasture and a switch from pasture to permanent cropping could result in a net carbon loss. While on-farm maize production would not currently be classified as a land-use change and hence New Zealand would not have to account for any loss in soil carbon, it would need to be considered from an environmental integrity perspective. If farmers relied on maize purchased off-farm, this might result in permanent conversions of pasture or other current land uses into cropland; if the conversion is from pasture this would result in a consistent loss in soil carbon. We have not quantified this effect but note that if this approach were to be promoted as a mitigation option, a more detailed study should consider changes in soil carbon, including implications for New Zealand's emission inventory and soil carbon accounting approach.

A second caveat is that putting more than a quarter of the land into maize implies a significant increase in the stocking rate on the remaining grazing land. This increases management challenges especially during wet seasons and increases risks to the farmer from potential maize crop failure or low yields.

Canterbury farm model

Canterbury farms on average rely much less on PKE than Waikato/BOP farms, and instead tend to rely on pasture silage, barley grain and fodder beet (the latter grown on-farm). One mitigation approach for the Canterbury region therefore would be to replace all bought-in pasture silage with bought-in barley grain, which has a lower nitrogen and higher ME content. This approach reduces both CH_4 emissions (via reduced dry matter intake to deliver the same energy in feed) and N_2O emissions (via reduced N intake and N excreta). Our modelling indicates that this would reduce biological on-farm emissions by 5%. Accounting for biological off-farm emissions (assuming they would all arise within New Zealand) slightly lowers the emission reduction to 4%, since the increased use of bought-in barley grain would slightly increase off-farm emissions.

A second mitigation option is the increased use of fodder beet, which is becoming popular on many Canterbury dairy farms and whose use is likely to increase further into the future even under business as usual. Fodder beet has a higher ME content and a lower N content than pasture silage. Our modelling indicates that if the amount of fodder beet were increased so that it fully replaced on-farm pasture silage and bought-in barley grain as well as most of the off-farm silage, this would reduce on-farm emissions by 1%.[6] If biological off-farm emissions are accounted for, the emission reduction is increased to 2% since this scenario also eliminates off-farm emissions arising in the base case from barley grain and most of off-farm pasture silage.

Economically, buying-in more barley grain is not profitable at current market prices, as profitability drops by 4% compared to the base farm, with an implied carbon cost of mitigation of \$108/tCO_2e if off-farm emissions are included. By contrast, increasing the on-farm production of fodder beet appears highly attractive, lifting the profitability of the farm by 12%. This would suggest that greater use of fodder beet could offer modest emission reductions while lifting profitability significantly.

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6 OVERSEER® assumptions regarding the ME or utilisation rates of fodder beet have not been published and hence there may be an inconsistency in the total amount of DM that FARMAX and OVERSEER® calculate to maintain total production (see Section 2.3.2). The amount of emission reduction calculated by the combined models is smaller than what would be expected based on first principles (which could in part be explained if the utilisation rate is lower in OVERSEER® than in FARMAX, as it is for barley grain or PKE).

However, pursuing this approach also has significant challenges. Significantly increasing fodder beet production has costs that are not fully captured by our modelling approach, including the risk of crop failure. In addition, given the low roughage content of fodder beet, increasing the fodder beet ratio in feed needs careful management to ensure a balanced diet including sufficient fibre content. The ability to fully replace all supplementary feeds with fodder beet also depends on the approach to wintering cows; farms that graze cows on an arable or sheep & beef property may not be able to make full use of fodder beet during winter.

Note that we have not considered any direct effects of fodder beet on CH_4 emissions. Experiments have shown that at a high rate of inclusion (>70% of total feed), fodder beet directly reduces CH_4 emissions by 30% or more. However, such high inclusion rates are difficult to manage in practice. In addition, the effect on net farm emissions of such high inclusion rates, including implications for N_2O emissions from intensive fodder beet feeding and concentrated urine deposition, have not been fully evaluated yet. We therefore consider the potential direct benefits of fodder beet on CH_4 emissions to still be at the experimental/pilot scale and have not included this in our model results.

Summary of low-N feeds

Our results indicate that increasing the use of low-N supplementary feeds could result in minor emission reductions if the supplements are grown on-farm, whereas the benefits if supplements are grown off-farm would depend on how off-farm emissions are accounted for. Quantification of emissions changes is subject to uncertainty given the inconsistent assumptions on ME, N content and utilisation rates between FARMAX and OVERSEER®. Our economic analysis suggests that increasing the use of maize silage in the Waikato/BOP farm model would have a minor effect on profitability, meaning that the moderate emission reduction that can be achieved is essentially cost-free. In the Canterbury farm model, increasing the use of fodder beet on-farm would reduce emissions only by a small amount but would substantially increase profitability. However, feeding fodder beet in situ over winter presents its own problems including potentially heavy pugging. Installing feed pads or barns to avoid this problem would have their own capital and labour requirements which are not included in our modelling approach.

The interventions as modelled do not change total production but only change input feeds and costs. Therefore, those approaches relying on additional bought-in feeds which were found to reduce profitability (e.g. barley) become even less attractive at low payouts for milk solids. In contrast, those that rely on supplements grown on-farm and increase profitability (Canterbury) would become particularly attractive at low payouts. At high payouts, the relative impact of either approach on profitability becomes smaller as overall profitability increases.

4.4 Once-a-day (OAD) milking

4.4.1 Scenario description

This scenario explores to what extent OAD milking could be an economically viable mitigation option. To do this, we established two twice-a-day (TAD) milking base farms in the Waikato/BOP running Friesian and Jersey cows. The Jersey base farm had the same physical parameters (area, pasture production) and supplementary feeds, but with lower milk production per animal and an increased stocking rate to consume the same amount of feed as the Friesian farm. A Jersey base farm was chosen in addition to a Friesian base farm to widen the options modelled based on animals with different size, yield and cost values, and because there is anecdotal evidence that Jersey cows may be more suited to OAD milking.

When switching those farms to OAD milking we considered the following key changes: [7]

- Milk yield per cow typically reduces when switching to OAD milking, although the extent of the drop depends strongly on specific farm settings, farmer skill and breed; in addition, there will be an adjustment period during which the herd can be selected for animals that perform better in OAD milking, meaning that there may be a greater drop in the first two years before a longer term performance can be established.
- Pasture production is assumed to remain the same as in the base case, but supplementary feeds were adjusted downwards to match the lower productivity
- Replacements rates decline and pregnancy rates increase
- Farm working expenses reduce, although the extent to which they reduce will depend on specific farm settings.

The net result of those changes will, in general, be a reduction in overall production and hence a reduction in emissions, along with reduced input costs. The net implications on profitability of this approach depends on whether the drop in overall input costs is greater or smaller than the drop in revenue from reduced milk production.

Given the as yet limited evidence base for OAD milking in New Zealand and the likely diversity of outcomes depending on farm-specific settings, we did not attempt to predict how much milk yield would in fact drop per cow. Rather, our modelling simply sought to determine by how much productivity per cow could drop when switching from TAD to OAD milking to maintain overall profitability. We then assessed the amount of emissions reductions resulting from such a drop in productivity and associated feed intake. The drop in productivity at which profitability remains the same can then be used as a basis for decision-making. If the farmers believe they can maintain production at or above this lower level under OAD milking, they may consider this an economically viable mitigation strategy; whereas if it is considered to not be possible to maintain productivity at this lower level, OAD milking would incur an additional cost.

The lower overall production has a small but positive correlation with lower N leaching and hence co-benefits for water quality. Note that depending on profitability and broader economic and environmental drivers, farmers could decide to purchase additional feed or adjust stocking rates further to optimise OAD systems; these further modifications were not modelled in this study.

4.4.2 Results and discussion

We emphasise that our modelling did not seek to determine by how much milk yields would in fact drop when switching from TAD to OAD milking, but rather by how much they could drop if profitability is to be maintained at base (TAD) levels, and the emissions reductions this would achieve. Our results indicate (see Table 10) that if profitability is to be maintained, productivity per animal could drop by about 7% and 15% for dairy farms using Friesian and Jersey cows, respectively, and emissions would reduce by about 6% and 7%.[8]

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7 Proceedings of the Once-a-Day milking Conference 2007; Report on meeting of the Southern NI OAD Discussion Group, 6th February 2013; Clark, D. A *et al.* (2006) A System Comparison of Once-versus Twice-Daily Milking of Pastured Dairy Cows. *J. Dairy Sci.* 89:1854-1862.

8 Note that these modelled differences between the two breeds do not imply that either breed is more or less suitable for OAD milking. They reflect different scenarios where smaller animals with a lower milk yield per animal were stocked at a higher rate than larger animals with a higher milk production per cow. These scenarios were constructed using similar costs structures but differences in the reduction in milk production at which profits is equalised is highly dependent upon how costs are scaled when milk production is reduced. The particular approach used here favoured the higher stocked lower productivity cows. Other approaches are possible and could yield different results.

Table 10. *Summary of key results for dairy, Once-A-Day milking. For details, see text.*

	SR (pastoral area)	Total Milksolids Production	Biological Emissions Total	Net CO2 change		Pastoral net profit	Drop in MS/cow that retains profitability
	Cows/ha	kgMS / % change	kg CO_2 equivalent	Absolute emissions	Emissions Intensity (milk only)	EBIT ($ pastoral total/yr)	
Switch to once-a-day milking							
Waikato/BoP							
Base – Friesians	3.0	139,432	1,556,688			$283,275	
OAD	3.0	130,202	1,468,743	-6%	1%	$283,072	-7%
Base – Jerseys	3.7	152,708	1,600,230			$292,411	
OAD	3.7	129,397	1,493,589	-7%	10%	$292,587	-15%

These results indicate that switching to OAD milking would offer modest but potentially low- or no-cost emissions reductions. The lower emissions arise because production and hence dry matter intake of an OAD system is expected to be lower than a TAD system operating on the same farm. The lower total production results in lower gross income, but this can be compensated for by reduced operational (mainly labour) costs for the OAD system. The cross-over point (i.e. the amount by which productivity per animal could be reduced while maintaining profitability compared to the base farm) is highly sensitive to assumptions regarding changes in costs, particularly but not exclusively labour. Details of implementation, and hence management decisions and farmer skill, would have a considerable influence on whether the generally favourable results obtained in our study could be achieved by a large fraction of farmers. If a larger-scale switch to OAD milking were to be considered, this would also have implications for breeding programmes and genetic selection for cows that can sustain a high milk yield at a reduced milking frequency. Given these issues, for which there is not yet a robust evidence base, our results should not be taken as a definitive assessment but rather as an order-of-magnitude indication of the three-way relationship between productivity, profitability and GHG emissions under OAD compared to TAD systems.

The amount by which productivity per animal can drop while maintaining overall profitability is highly dependent on the payout per kg of milk solids. At low payouts, a greater drop in productivity can be sustained for the farm to break even with its TAD milking counterpart, whereas at high payouts, the drop is much smaller. The attractiveness of OAD milking is therefore highly dependent on longer term expectations about dairy MS prices.

More detailed modelling with a range of actual farms, informed by the growing experience on OAD milking operations, would be necessary before these numbers could act as a guide to their actual viability. We also stress that our modelling did not consider the transition from TAD to OAD milking. During this transition phase, milk yields could potentially drop more as farmers optimise their systems and remove cows from their herd that are not well suited to OAD milking. This transition period exposes farmers to additional risks, which could present barriers to a more widespread change even if the longer term expectations were that successful implementation was possible.

Some research has shown selecting individual cows well suited to OAD could minimise the reduction in milk production and hence loss in gross earnings, but this would at the same time diminish the GHG reduction benefit as dry matter intake would be maintained at a level more similar to TAD. Nonetheless, new diverse farming systems could emerge driven by the OAD concept, based on smaller herds using existing arable and sheep & beef farms.

If OAD milking were to be scaled out to more farms, this would also have implications for the rural labour force associated with dairy operations, although it could also address issues around getting and keeping labour on dairy farms, as OAD milking could offer opportunity for specialist milk harvesters employed in school hours. If a move to OAD milking results in reduced national total milk production, this could affect New Zealand's global position as a dominant exporter of milk, although total production is more likely to be determined by other economic and environmental restrictions or opportunities for further dairy conversions.

4.5 Remove N fertiliser

4.5.1 Scenario description

In this scenario, all nitrogen fertiliser application was removed. Stock numbers were maintained but overall pasture production was reduced due to the lower N inputs, and therefore production levels decreased slightly (assuming that body condition score and breeding performance remained unaffected). This analysis was conducted for Northland, Waikato/BOP, Taranaki, Canterbury, and Southland.

In practice, farmers could choose to increase use of supplementary feeds purchased off-farm to counteract the reduced pasture production, although this would often be at a higher cost relative to using nitrogen fertiliser. Also clover content of pastures would increase over time if no N fertiliser was used. These could have implications for total feed intake and N content of the diet and hence N excretion and N_2O emission rates. These options were not modelled explicitly.

Emissions reductions in this scenario result from two factors; one is the reduced overall feed intake and production, and associated reductions in CH_4 and N_2O emissions, and the other is the reduced N_2O emissions from fertiliser use. Even though overall production is reduced, the net impact on profitability depends on the extent to which lower product revenue can be offset by lower input costs for fertiliser (i.e. how close the actual quantity of N fertiliser use is to its economic optimum). This differs between regions (and between farms within regions).

This scenario could have potentially strong co-benefits for water quality from N leaching in some catchments. However, any associated increase in the clover content of pastures would increase N content of the diet and hence N leaching rates. Such a change in pasture composition was not taken into account in our modelled scenarios, but we note that this scenario could be combined with a reduction in stocking rates as white clover has a higher feed intake potential and thus fewer cows need to be carried for a given production of MS/ha. However, we did not model such a combined scenario since this would require an optimisation approach. Freshwater reform may drive some of these changes in some catchments independent of any climate policy goals.

4.5.2 Results and discussion

Our model results (see Table 11) show that eliminating N fertiliser from dairy operations would result in measurable reductions of biological GHG emissions of between 6 and 14% in different regions. This drop is predominantly the result of reduced overall production (which declines by between 4 and 14%), with additional benefits from lower N_2O emissions from reduced fertiliser use.

Based on our model setup, the approach would have a very minor (but positive) effect on profitability in Northland, Canterbury and Southland. While our study does not indicate that removing all fertiliser input would be economically optimal for those farms, it does suggest that these regions are currently on average operating above the economically optimum level of N fertiliser use. Hence emissions could be reduced in those regions by reducing fertiliser application below current levels without economic penalty. By contrast, farm profitability drops by 24% in the Waikato/BOP and by 14% in Taranaki if N fertiliser is eliminated, implying a carbon cost of mitigation in excess of \$200/tCO_2e. These specific numbers are subject to uncertainty introduced by the specific farm model design and without further detailed examination it should not automatically be inferred that those regions currently operate at or even below the economically optimum level of fertiliser use.

Table 11. *Summary of key results for dairy: remove N fertiliser, and remove summer crops.*

	Stocking rate (pastoral area)	Total Milksolids Production	Biological Emissions Total	Net CO_2 change		Pastoral net profit	
	Cows/ha	kgMS	kg CO_2 equivalent	Absolute emissions	Emissions Intensity	EBIT ($ pastoral total/yr)	Carbon Cost of Mitigation ($/T)
Cut/reduce N fertiliser inputs							
Northland							
Base model	2.3	98,462	1,267,245			$132,435	
Eliminate N fertiliser	2.3	89,653	1,129,275	-11%	-3%	$135,270	-$21
Waikato/BoP							
Base model	3.0	139,432	1,647,093			$311,436	
Eliminate N fertiliser	3.0	121,941	1,487,685	-10%	2%	$236,406	$471
Taranaki							
Base model	2.9	115,699	1,315,020			$269,115	
Eliminate N fertiliser	2.9	98,972	1,141,665	-13%	-1%	$232,890	$209
Canterbury							
Base model	3.6	333,781	3,787,632			$586,496	
Eliminate N fertiliser	3.6	321,249	3,551,456	-6%	-3%	$593,920	-$31
Southland							
Base model	2.9	225,899	2,661,435			$348,681	
Eliminate N fertiliser	2.9	210,554	2,456,742	-8%	-2%	$349,959	-$6
Remove summer cropping							
Northland							
Base model	2.3	98,462	1,267,245			$132,435	
Remove crop	2.3	91,058	1,219,590	-4%	3%	$141,345	-$187
Waikato/BoP							
Base model	3.0	139,432	1,647,093			$311,436	
Remove crop	3.0	133,182	1,537,623	-7%	-2%	$297,045	$131
Taranaki							
Base model	2.9	115,699	1,315,020			$269,115	
Remove crop	2.9	112,585	1,308,825	-1%	2%	$265,020	$661
Canterbury							
Base model	3.6	333,781	3,787,632			$586,496	
Remove crop	3.6	324,824	3,734,736	-1%	2%	$549,840	$693
Southland							
Base model	2.9	225,899	2,661,435			$348,681	
No on-farm grass silage	2.9	228,155	2,671,659	0%	0%	$378,288	Not a mitigation

Removing N fertiliser would increase the farm management skills necessary to maintain the productivity indicated by the model, particularly since this would reduce flexibility for farmers to cope with climate variability by capitalising on highly productive seasons to compensate for less productive ones.

4.6 Remove on-farm cropping

4.6.1 Scenario description

In this scenario all on-farm cropping was removed. Stock numbers and supplementary feeds purchased off-farm were maintained as in the base farm system, but production levels decreased until a feasible solution was found.

Note that in practice, farmers could choose to increase the use of supplementary feeds purchased off-farm to counteract the reduced production of supplementary feeds on-farm. This was not modelled explicitly.

Emission reductions in this scenario result mainly from the lower overall feed availability and hence reduced production and associated CH_4 and N_2O emissions. Even though overall production is reduced, the net impact on profitability depends on the marginal profitability of supplement production on-farm. This differs between regions and individual farms within regions.

Depending on the crop, this option could have positive or negative implications for water quality, depending on the N content of the summer crop and of pasture grown instead of the crop.

4.6.2 Results and discussion

Our model results (see Table 11 above) indicate that removing on-farm cropping, and reducing total production to reflect the lower feed supply, would have a noticeable effect on emissions and production in Northland and the Waikato, where emissions would reduce by 4% and 7% and production by 8% and 4%, respectively. Effects on emissions in other regions (Taranaki, Canterbury and Southland) would be minor, with emissions changes of less than 1.5%.

For Northland, our modelling suggests that removing crops would be economically beneficial, with profitability increasing by 7%. By contrast, removing crops in the Waikato would result in a decline in profitability by 5%, with an implied carbon cost of mitigation in excess of \$100/tCO_2e. We cannot rule out that the results are to some extent due to the specific model design and how the farm system is balanced after removal of the crops. We do however note that this result is consistent with the modelling of low-N feeds for the Waikato, which indicated that increasing (rather than eliminating) on-farm production of maize silage would maintain production levels and be economically beneficial.

An additional factor to be considered with regard to on-farm crops is that in some situations they are an integral component of pasture renewal. Pasture renewal in turn is a key to maintaining pasture productivity across the farm. In this modelling exercise the possible benefits of crops for pasture productivity were not taken into account. We also note that in our model, we assumed that where removal of on-farm crops results in lower DM intake, this translates into lower total milk production per animal. In practice, some animals may continue to produce milk but loose body condition if crops are removed. The scenario modelled may therefore not necessarily reflect the practical outcome on farms, depending on farmer skill and genetic make-up of herds.

5. Quantitative mitigation options for sheep & beef systems

5.1 Land-use change: forestry

5.1.1 Scenario description

Similar to the dairy modelling, we explored the extent to which land-use change, from sheep & beef production to forestry on a proportion of the farm, could help reduce emissions without being detrimental to farm profitability. As for dairy, a range of sub-sets were modelled:

(i) The first set involved introducing a significant proportion of forestry (10, 20, 30%) in the North Island and South Island hill country models. The hill country base models were each set up with a range of topographical units. For the North Island model the units were steep (45%), rolling (45%) and flat (10%) topography. For the South Island model the units were steep (21%) rolling (26%), flat (13%) and tussock (40%). In all instances, as forestry was progressively introduced to the base farm model (up to 30% of the total farm area) it was allocated to the steep land category first. In each case the mix of enterprises remained constant; both sheep and cattle stock numbers reduced but by less than the percentage of forestry. This resulted in increased stocking rates on the pastoral area compared to the base farm (e.g. for the North Island hill country farm from 8.1 stock units/ha in the base case to 9.1 stock units/ha at 30% forestry). Per hectare pasture growth on the pasture area remained at the base level. The net effect of these adjustments was a reduction of total farm production, but by less than the percentage of land put into forestry (i.e. an increase in production per ha of the remaining pastoral land).

(ii) We also tested one scenario where stocking rates and productivity were not increased significantly on the remaining pastoral area and hence total farm production fell by almost the same percentage as the area of land put into forestry. This scenario was only tested for the 10% forestry option and only for the North Island hill country farm, using the same base farm as in (i) above.

(iii) The third scenario, based on earlier modelling conducted for MPI, involved planting forestry only on marginal land, to see to what degree more moderate forestry, targeted to the least productive areas of the farm, could help offset GHG emissions on-farm. For this scenario the base farm was modelled as one topographically homogenous unit (in contrast to (i) and (ii) above) and the scenario was implemented by placing approximately 5% of the pasture area into forestry. Pasture growth on the remaining pastoral area was increased by 1.5-2%, based on the assumption that the 'marginal' land retired to forestry produced only two thirds of the dry matter per hectare compared to the farm as a whole, and hence the remaining pastoral area had a slightly higher pasture growth. All stock numbers were then reduced equally to create a feasible feed budget. The remaining pastoral farm system was intensified very slightly to maintain overall production levels. This scenario was tested for both hill country and intensive finishing farms in the North and South Island.

Removing less productive pasture areas from grazing and planting in trees will reduce animal production to a greater or lesser extent (especially where the forested areas have limited pasture production potential). This contributes to net GHG emission reductions in combination with carbon sequestration by the trees. Reduced animal production clearly reduces revenue, but may be partially offset by reduced input costs to the farm system combined with a revenue stream from the forestry operation (unless planted for conservation purposes). In addition, forestry holds the prospect of additional revenue from carbon sequestration by the trees.

Practical difficulties do exist, however. For example the farm has fixed costs which still need to be covered in the short term by revenue from a reduced pasture area and the cash flow characteristics of long-term forestry may be difficult to manage especially for the first tree rotation. Potential returns from hill country forestry blocks may also be limited by block size, remote location and steep topography. These factors could not be taken into account explicitly in our modelling but need to be considered, based on specific farm profiles, if and where such an approach were to be pursued.

5.1.2 Results and discussion

Scenario (i): introduce forestry and intensify production on reduced pastoral land area

Similar to the results for dairying, our modelling indicates that replacing significant areas of sheep & beef land with radiata forestry would reduce net GHG emissions significantly but would also reduce profitability for the farm systems as a whole. For details, see Table 12.

The emission reductions that would be achieved from sheep & beef farms are significant, even if only the 'safe carbon' sequestration potential is assumed and the loss of soil carbon is accounted for. The emissions reduction results mainly from the carbon sequestration by trees, but part of the emissions reduction also arises from allowing the total production, and hence dry matter intake, to drop for the pastoral operation. Placing 10% of the farm area into forestry would reduce net emissions from the North Island hill country farm by 25%, and from the South Island hill country farm by 14% (the emission reduction is lower because the 10% is applied only to non-tussock land). By contrast, if the 28-year sequestration potential is assumed, then placing 10% of the North Island hill country farm into forestry would make the farm carbon neutral and at 30% would reduce net emissions by 311% (i.e. a net carbon sink). For the South Island hill country farm, placing 10% of the non-tussock land into conservation forest would reduce net emissions by 73%, and at 30% would reduce emissions by 191%.

Placing sheep & beef land into forestry results in a loss of profitability because the *average* sheep & beef farms in both North and South Island hill country are more profitable than the assumed annuities from forestry. In addition, total costs do not scale back proportionally to a reduction in the pastoral land area due to the inflexibility of fixed costs. The introduction of forestry therefore results in a disproportionate reduction in EBIT from the pastoral operation, which affects the profitability of the farm system as a whole even if forestry annuities are comparable or slightly higher than that of the sheep & beef enterprise. For example, for the North Island hill country, placing 10% of the land into forestry reduces EBIT from the pastoral operation by 16%. Even if the forestry annuity is assumed to be similar to the profitability of the base sheep & beef farm, the profitability of the combined pastoral plus forestry farm system still drops by 6%.

Nonetheless, the implied carbon cost of mitigation is generally much lower than for the same approach on dairy land. If only the 'safe carbon' sequestration potential is used and loss of soil carbon is included, implied carbon costs of mitigation are \$35-\$40/tCO_2e for the North Island hill country farm for 10%-30% of the land placed into forestry, and \$37-\$47 for the South Island hill country farm. These costs are based on annuities for small-block farm forestry from Journeaux et al. (2016). These implied carbon costs are sensitive to the assumed annuity from the forestry operation: the implied carbon costs of mitigation would drop to about \$20/tCO_2e for the North Island hill country farm if a more optimistic commercial forestry annuity of about \$280/ha based on Dowling et al. (2017) is assumed.

Note that the implied carbon cost of mitigation is sensitive to assumed schedules for meat and wool, because the modelled farms are not able to maintain the total production levels of the base farm when forestry is introduced, despite intensification of operations on the remaining pastoral land. As a result, the economic penalty from increasing forestry is sensitive to commodity prices. If prices are 30% lower, the implied carbon cost of mitigation would drop from \$35-40 to less than \$20/tCO_2e for the North Island hill country farm, whereas if prices are 30% higher, it would rise to about \$60/tCO_2e. This indicates that expectations about future prices have a significant influence on the potential attractiveness and cost-effectiveness of this approach, and could hinder adoption because forestry reduces flexibility for farmers to respond as and when prices change.

If the full conservation sequestration potential is assumed (including a negative annuity of \$144/ha associated with establishment and management costs, based on Journeaux et al. (2016)), then the carbon cost of mitigation would \$16-17/tCO_2e for both the North and South Island hill country farms. The cost is also sensitive to meat and wool schedules in relative terms, but varies much less in absolute terms, from \$12/tCO_2e if schedules are 30% lower to \$21/tCO_2e if schedules are 30% higher. This suggests that committing to conservation forestry and relying on carbon prices only may be a less risky approach to mitigation than a reliance on forests for harvest, especially if only the 'safe carbon' sequestration potential can be claimed.

__Table 12.__ Summary of key results for sheep & beef, land-use change into forestry. Results are given for the 'safe carbon' sequestration potential, and for some scenarios for the full 28-year sequestration potential (light grey shaded rows). For details, see text.

	Stocking rate (pastoral area)	Biological Emissions Total	Net CO_2 change incl. carbon sequestration from forestry		Pastoral net profit	Enterprise net profit	
	SU/ha	kg CO_2 equivalent	Absolute emissions	Emissions Intensity	EBIT ($ pastoral total/yr)	EBIT (pastoral + forestry annuity)	Carbon Cost of Mitigation ($/t)
NI hill country – large-scale forestry, increase stocking rate to maintain (or almost maintain) production							
Base model	8.1	1,806,896			$141,451	$141,451	
10% Forestry	8.4	1,652,574	-25%	-19%	$118,214	$125,113	$37
28-yr seq. pot.			-105%	(N/A)		$110,856	$16
20% Forestry	8.7	1,526,868	-48%	-38%	$94,452	$108,249	$38
30% Forestry	9.1	1,403,717	-71%	-62%	$71,543	$92,239	$39
28-yr seq. pot.			-311%	(N/A)		$49,468	$16
10% Forestry, lower total production	8.2	1,604,540	-27%	-20%	$111,068	$118,004	$48
SI hill country – large-scale forestry, increase stocking rate to maintain production							
Base model	7.6	3,186,480			$173,408	$173,408	
10% Forestry	7.9	2,977,040	-14%	-10%	$147,123	$154,018	$44
28-yr seq. pot.			-73%	-72%		$134,866	$16
20% Forestry	8.2	2,819,960	-24%	-16%	$124,819	$137,364	$46
30% Forestry	8.5	2,670,360	-35%	-25%	$103,174	$121,183	$47
28-yr seq. pot.			-191%			$71,157	$17
NI intensive – plant trees on marginal land, maintain production							
Base model 290 ha		1,139,816			$90,190	$90,190	
11 ha forestry		1,103,926	-7%	-4%	$87,885	$91,845	-$20
28-yr seq. pot.			-34%	-32%		$86,301	$10
NI hill country – plant trees on marginal land, maintain production							
Base model 511 ha		1,806,896			$141,547	$141,547	
26 ha forestry		1,744,350	-12%	-8%	$134,345	$137,855	$18
28-yr seq. pot.			-52%	-51%		$130,601	$12
SI intensive – plant trees on marginal land, maintain production							
Base model 351 ha		1,220,076			$120,744	$120,744	
18 ha forestry		1,177,605	-10%	-5%	$113,886	$117,054	$30
28-yr seq. pot.			-45%	-42%		$111,294	$17
SI hill country – plant trees on marginal land, maintain production							
Base model 1496 ha		3,183,488			$176,528	$176,528	
75 ha forestry		3,135,616	-8%	-7%	$179,071	$185,130	-$35
28-yr seq. pot.			-58%	-57%		$168,300	$4

Overall, our results suggest that introducing a significant forestry component into sheep & beef operations would result in a loss of profitability but would deliver emission reductions at implied carbon prices that either are already in existence or could well be reached if countries seek to deliver on their commitments under the Paris Agreement. A greater use of forestry would be attractive for farms that are at the lower end of the range of profitability, which still would represent a significant overall mitigation potential given the large land area. However, it was beyond the scope of this report to quantify the national-scale mitigation potential as this would require detailed analysis of sheep & beef farm statistics. Financial assistance to plant forests (e.g. the Afforestation Grant Scheme) and/or to manage farms through the earlier years of the rotation, would make this mitigation option more financially attractive. There are strong co-benefits in reducing hillslope erosion and sediment and nutrient emissions to water.

In addition, we note that sheep & beef farms are highly heterogeneous in their economic performance, and thus the notion of an 'average' farm and 'average' profitability is somewhat problematic. Added to this the profitability effect of planting forestry on sheep & beef farms also varies. The modelling here assumed average levels of profitability. Examination of the distribution of profitability of hill country farms (Beef + Lamb NZ Economic Service) indicates that forestry is likely to be more profitable, on an annuity basis, than (roughly) the bottom 30% of farms, and hence forestry on these properties could enhance their overall profitability.

However, the increased intensity of the pastoral enterprise in scenario (i) places additional demands on farmer skill to ensure the increased production per pastoral hectare is in fact achieved. This additional skill requirement has not been included as a cost in our modelling but could present a barrier to actually achieving the modelled outcome in practice.

Widespread land-use change (at 30% of farm area) from sheep & beef systems towards forestry would have implications for rural labour supply and demand, with consequent social impacts. These issues have not been considered in this report but would form an important element for any regional strategy that would seek to achieve such an outcome.

Scenario (ii): introduce forestry without significant intensification on reduced pastoral land area

Profitability of the North Island hill country farm would be reduced more if operations on the remaining pastoral land area are not intensified. This is because a significant component of fixed costs remain unchanged. In other words, if forestry is introduced into the farm system, it is economically beneficial for farmers to seek to intensify their operations on the remaining pastoral area rather than simply scale back their operations. Without this move to intensification on the remaining pastoral area the viability of introducing forests would be questionable for the vast majority of beef and sheep farmers.

Scenario (iii): introduce forestry on marginal land only

Results from this scenario are similar[9] to those from scenario (i), except that changes in profitability are smaller (less than 5% compared to the base farms). This is because removing less productive land into forestry, along with assumed higher productivity of the remaining land, results in a lesser decline or even increase in the profitability of the pastoral enterprise. For the North Island intensive finishing farm and the South Island hill country as characterised in our model, the profitability of the combined pastoral and forestry farm system increases relative to the base farm.

Net GHG emissions in this approach are reduced by 7-12%, with an implied carbon costs of mitigation below \$30/tCO_2e if the 'safe carbon' sequestration potential is assumed and loss of soil carbon is accounted for. If the full conservation sequestration potential is assumed, net GHG emissions would be reduced by 34-58% with an implied carbon cost of mitigation well below \$20/tCO_2e for all four systems modelled for this scenario (North and South Island hill country and intensive finishing systems).

These results suggest, unsurprisingly, that focusing forestry operations on the least productive pastoral land can help reduce negative economic impacts resulting from the introduction of forestry, and could even benefit the pastoral enterprise where this might reduce inefficiencies. Even at relatively small scales, emissions reductions from sheep & beef farms could be significant if forests are planted for conservation purposes. However, we must emphasise that these results apply only to the highly generalised farm systems as set up in our model; the diversity of actual farm systems across New Zealand means that it is difficult to determine the number of actual farms where those

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[9] Note that this scenario was run using slightly different farm assumptions, based on Journeaux et al. (2016) and a different version of FARMAX and OVERSEER®, hence results are not strictly comparable to scenarios (i) and (ii).

findings might apply in reality, as this would require a much more detailed analysis of actual farm data and statistics.

Planting trees on marginal land can also limit access for harvesting or increase costs, which makes the viability of this approach highly dependent on specific farm characteristics. Choices about whether to plant trees for harvest or conservation purposes will thus depend not only on farmers' interests but also physical access and associated costs as well as environmental regulations affecting harvesting options. If trees are planted for conservation purposes, then radiata pine is not necessarily the species of choice and hence the carbon sequestration rates used in this report for conservation forests (including the 28-year time horizon) should be taken as indicative only.

5.2 Reduce stocking rates / increase productivity

5.2.1 Scenario description

As for dairy systems, reducing stocking rates could allow increasing productivity per animal while reducing GHG emissions and roughly maintaining overall production. We explored this option for the North Island and South Island intensive finishing models.

For the North Island model, lambing percentage and finishing livestock growth rates were increased by 10% compared to the base model, supported by a reduction in ewe and cattle numbers to release sufficient additional pasture per animal to achieve these goals; increased feed demand in the spring in particular necessitated a reduction in capital stock wintered. For the South Island model, ewe numbers were reduced and lamb carcase weights increased (based on improved lambing percentage and greater pasture availability per lamb). The North Island model had both finishing and dairy heifer grazing enterprises present, whereas the South Island model had only dairy heifer grazing as a cattle enterprise.

We also explored, through a separate set of scenarios conducted for an earlier study, the implications of reducing stocking rates *without* an attendant increase in productivity per animal by also reducing other inputs. This was done for both the North Island and South Island hill country and intensive finishing systems.

5.2.2 Results and discussion

Our results (see Table 13) indicate that reducing stocking rates and increasing productivity per animal in intensive finishing systems could result in moderate to minor reductions of biological GHG emissions, but result in a significant increase in profitability (therefore increasing flexibility for farmers to undertake other, potentially more costly mitigation measures, although this would depend on incentives).

For the North Island intensive finishing system, increasing productivity while reducing stock units by 6% resulted in a reduction of GHG emissions by 2% but increased profitability per hectare by 28%. For the South Island intensive finishing system, increasing productivity of the sheep enterprise while reducing sheep stock units by 8% resulted in a reduction of GHG emissions by 5% but increased profitability per hectare by 16%.

Variations in meat and wool prices affect how much profitability increases in absolute terms, with higher payment schedules resulting in a greater absolute increase in profitability; on the other hand, the relative increase in profitability is much more significant if schedules are low. For example, if schedules are 30% below their current average, increasing productivity would increase the profitability of the South Island intensive finishing system by 54%, compared to by 16% under current average prices. The North Island intensive finishing system returns a loss if schedules are 30% below their current average but would return to profit with increased productivity.

The modelled increase in profitably raises the question of why this is not happening already since it implies sub-optimal farm operations. Practical implementation of these scenarios include potential difficulty in converting the pasture consumed in the base models into increased finishing stock performance. While there are examples of this approach being employed successfully in the sheep & beef industry, universal adoption would likely be limited by specific farm characteristics, and farmer aspirations and skills. We did not model the effect of a potential drop in pasture quality (as for dairying) but this is a risk that will affect adoption rates and relies on farmer skills to manage this risk effectively in the face of climate variability and long-term change.

Table 13. *Summary of key results for sheep & beef, reduce stocking rate and increase productivity.*

	Stocking rate (pastoral area)	Biological Emissions Total	Net CO_2 change		Pastoral net profit	
	SU/ha	kg CO_2 equivalent	Absolute emissions	Emissions Intensity	EBIT ($ pastoral total/yr)	Carbon Cost of Mitigation ($/t)
NI intensive						
Base model	9.0	1,129,260			$90,146	
Reduce SR / incr. productivity	8.5	1,107,220	-2%	-8%	$115,048	-$1,130
SI intensive						
Base model	9.2	1,225,692			$120,523	
Reduce SR / incr. productivity	8.8	1,168,830	-5%	-9%	$139,834	-$340
NI intensive: decrease stocking rate without increasing productivity						
Base model		1,139,816			$90,190	
Reduce SR / scale back farm		1,096,432	-4%	5%	$80,910	$214
NI hill country: decrease stocking rate without increasing productivity						
Base model		1,806,896			$141,547	
Reduce SR / scale back farm		1,721,416	-5%	3%	$136,437	$60
SI intensive: decrease stocking rate without increasing productivity						
Base model		1,220,076			$120,744	
Reduce SR / scale back farm		1,137,240	-7%	3%	$89,856	$373
SI hill country: decrease stocking rate without increasing productivity						
Base model		3,183,488			$176,528	
Reduce SR / scale back farm		2,864,840	-10%	0%	$149,600	$85

On the other hand, the use of superior genetic stock and improved farm management practices could achieve additional gains in lambing percentages and other animal traits, although these options were not modelled explicitly. For example, the increases in lambing percentage were generated in the modelling by increasing ewe mating weight, and it was assumed the advantages of this would be captured through increased ovulation rate, and lambing and weaning rates. Stocking rates were decreased to compensate for the higher feed demand of the heavier ewes as well as the higher feed demand in spring/summer to finish the increased number of lambs. Use of more advanced ewe genetics would not necessitate the increase in ewe liveweight, and ewe numbers would not need to be reduced to the same extent, which should have production and financial benefits. An increase in productivity as envisaged in this scenario would open up a range of subsequent decisions that were not modelled explicitly, and would rely on individual farm optimisation decisions. Furthermore, climate variability (especially the risk of drought) could alter the viability of the approach, and would also depend on the ability of a farmer to sustain operations through one or two 'bad' years before being able to recover during more favourable conditions. However, for the purpose of this report, we have not sought to model climate variability explicitly, as the consequences will often by highly farm-specific.

The above discussion at least in part underpins the philosophy of the PGP-funded Red Meat Profit Partnership (RMPP). Beef + Lamb NZ statistics demonstrate that there is a wide distribution of sheep

& beef farmers with regard to production and financial performance. Farmers who successfully implement good pasture and animal husbandry, business principles, and configure and manage their farming systems according to the available resources and market opportunities tend to be at the most profitable end of the distribution. The RMPP is about determining how to move the whole normal distribution, and the shape of it, towards the high-profitability end. Farmers at that end have more opportunity to manage the environmental implications of their farming systems.

We note that the productivity gains assumed in this scenario would be quite likely to occur over time simply as part of gradual improvements in performance of the sector that occur under business as usual. What our modelling suggests is that these improvements could be greatly accelerated and result in both improved economic and environmental outcomes.

The picture is sharply different if it is assumed that stocking rates are reduced without an attendant increase in productivity, i.e. if operations are simply scaled down.[10] In this scenario, GHG emissions decreased by greater amounts (from 4% in the North Island intensive finishing system to 10% in the South Island hill country system), because reduced stocking rates were not counterbalanced by increased productivity and hence emissions per animal. However, profitability of all enterprises declined, in most cases by greater amounts than the reduction in GHG emissions, from 4% for the North Island hill country farm to 26% for the South Island intensive system. The implied carbon costs of mitigation for this approach range from \$60/tCO_2e for the North Island hill country system to more than \$200/tCO_2e for the North and South Island intensive finishing systems.

While results from the two contrasting approaches (reduction in stocking rate with either compensating increases in productivity or not) are not strictly comparable, they do strongly suggest that simply scaling back sheep & beef operations is not a cost-effective mitigation measure. In addition, this approach poses not only economic but also management challenges. Reduced animal feed demand without concurrent reductions in feed supply will lead to supply demand inequalities and reduced pasture utilisation particularly in the spring 'flush', pasture quality will decline and some of the issues outlined below will eventuate.

One of the main drivers of pasture production on hill farms are phosphorus and sulphur fertiliser inputs to the legume-based pastures[11]. If these are reduced in line with lower product output, pasture production will decline over time because of reduced symbiotic N fixation, pasture composition will revert to less desirable species, and pasture vigour will be reduced. 'Depowering' hill country farms in this way would in many instances reintroduce historical management issues. These include more marked differences in seasonal growth exacerbating feed supply/demand imbalances, reduced feed quality and inability to maintain performance of both breeding and finishing stock, and increased difficulty in keeping shrubby weeds under control.

Management difficulties associated with lowering stocking rates are mitigated to an extent on intensive finishing farms with easier topography; in these cases the amount and seasonality of feed supply can be better managed through such practices as pasture topping, pasture conservation, cropping, and feeding out conserved feed. However, the most efficient use of pasture is *in situ* grazing in a high quality state, at the time it is produced. These afore-mentioned practices are relatively expensive and an increased need for their use would inevitably reduce profitability. Maintaining pasture quality under a grazing regime at lower stocking rates relies on farmer skill, which means that broader adoption of such approaches is likely dependent on increasing farmer skill across the industry. Those options are also generally much more limited on hill country farms.

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10 Note these results are based on an earlier modelling study (Journeaux et al. 2016) and hence results are not directly comparable with the results for decreasing stocking rate and increasing productivity, as model versions and some farm assumptions are slightly different.

11 Coupled with good subdivision and grazing management

5.3 Remove breeding beef cows

5.3.1 Scenario description

This scenario explores to what extent replacing breeding beef cows (a relatively low-profitability system) with a higher profitability finishing system relying entirely on bought-in cattle from the dairy industry could reduce emissions for both North Island and South Island hill country modelled farms. Breeding cows and replacement heifers were replaced with the required number of bought-in animals (bought as 3-month weaners, at 100 kg liveweight) to achieve the performance as outlined below. Pasture growth, sheep numbers and their performance remained unchanged (compared to the base models) in this scenario.

The main scenario focused on finishing bulls and was run for both North Island and South Island hill country farms. However, given management challenges associated with bulls and also paying regard to systems currently employed in practice, we considered a total of three variations to this basic approach for the North Island model farm:

(i) Finishing bulls
- Finishing bulls – (290-300 kg CW) 68% of bought in cattle
- Finishing heifers – (210-220 kg CW) 32% of bought in cattle

(ii) Store bulls
- Store bulls – (390 kg LW) 78% of bought in cattle
- Finishing heifers – (220kg CW) 22% of bought in cattle

(iii) Finishing steers
- Finishing steers – (310+ kg CW) 77% of bought in cattle
- Finishing heifers – (220 kg CW) 23% of bought in cattle

For the South Island model the only scenario modelled was the finishing bull scenario (i), but with bulls constituting a more significant part of the enterprise, representing 76% of total cattle numbers.

5.3.2 Results and discussion

Our results (see Table 14) show that the emission reductions that can be achieved with this approach are moderate (3-4%) for the North Island model and negligible (1%) for the South Island model. However, they do result in significant improvements in profitability of 51-68% above baseline for the North Island hill country farm (depending on the focus on finishing or store bulls or steers), and well over 100% for the South Island hill country farm. The profitability of these approaches does not depend strongly on assumptions about meat prices. The reason why absolute emissions change little is that the total dry matter eaten by animals remains similar to the base farm. However, this dry matter is converted much more effectively into meat production, rather than maintenance of breeding cows, resulting in a significantly greater drop in emissions intensity (i.e. total emissions divided by total amount of meat produced).

As for the scenario that improves productivity by dropping stocking rates (5.2), this implies that a shift away from breeding beef cows would not result in a major reduction in emissions per se, it would influence system flexibility (see below) for farmers individually, as well as for the beef industry as whole. It would also significantly reduce emission intensity of beef production.

The large modelled increases in profitability naturally raise the question as to why such an approach is not being adopted more widely already. Our study in itself does not provide answers to this, but we can offer a number of considerations that would need further exploration.

Table 14. *Summary of key results for sheep & beef, replace breeding cows with surplus dairy animals.*

	Stocking rate (pastoral area)	Biological Emissions Total	Net CO_2 change		Pastoral net profit	
	SU/ha	kg CO_2 equivalent	Absolute emissions	Emissions Intensity	EBIT ($ pastoral total/yr)	Carbon Cost of Mitigation ($/t)
NI hill country						
Base model	8.1	1,805,363			$141,451	
Finishing bulls		1,748,131	-3%	-27%	$236,279	-$1,245
Store bulls		1,728,202	-4%	-26%	$237,038	-$1,655
Finishing steers		1,728,713	-4%	-14%	$213,880	-$1,162
SI hill country						
Base model	7.6	3,186,480			$173,408	
Finishing bulls		3,150,576	-1%	-44%	$458,982	-$7,954

One aspect is that finishing stock, especially bulls, require different farm management practices and infrastructure compared to beef cows. The direct costs of any infrastructural improvement (e.g. electric fencing, improved water supply) were not taken into account in our study. In addition operating improved farm systems to handle those animals does require higher farmer skill and commitment, which cannot necessarily be translated into simple economic terms but also reflects farmers' aspirations and access to training. Some sheep & beef farmers actively dislike farming bulls because of some of their behavioural characteristics, and the damage they can cause to infrastructure and the integrity of pastures and soils.

Replacing breeding cows with finishing stock does have some implications for pasture, farming system and risk management. Breeding cows are often used to 'clean up' low quality pastures, particularly over the autumn and winter, and to control woody weeds; their replacement with finishing stock would largely remove this option. On the other hand, in drought-prone regions breeding cows are not as flexible as finishing stock where the feed demand can be more readily changed through buying and selling. As for the increased productivity options (see 5.2 above), success of replacing breeding cows with finishing cattle will depend on farm characteristics (finishing cattle scenarios are better suited to well-developed properties) and farmer aspirations and skills.

Our scenario here relies on surplus dairy calves as finishing stock. At present, the dairy herd produces an estimated 2 million surplus calves which are processed as bobby calves, indicating that there is significant potential to adopt the scenario outlined here more widely across the beef sector. However, we emphasise that we have not undertaken a national-scale approach here, as a greater demand for surplus dairy calves could increase their prices and increase costs for management systems, and changes in prices driven by climate variability. Our modelling study assumed that calves are bought as 3-month weaners, implying a gap of 3 months between birth and purchase. As calves would feed mostly on milk plus some concentrates the emissions caused during this period would be negligible, but additional infrastructure and management might be required if the transfer of bobby calves to the beef sector were to be up-scaled significantly.

Various initiatives have been initiated already to further increase the value of dairy industry surplus calves to the beef industry. These include use of semen from beef sires with proven performance in terms of calving ease, growth rate and carcase composition over a proportion of cows in the dairy herd. Industry initiatives to use semen from sires with potential to produce meat with greater marbling propensity and increased market value are also underway. One of the most promising of these involves use of Wagyu semen over dairy cows to produce offspring with the ability to produce high value highly marbled beef from pasture-based systems.

5.4 Other management changes

5.4.1 Scenario description

Finally, we explored a range of additional management scenarios:

(i) **Alter sheep to cattle ratio.** In this scenario sheep numbers were increased by 20%, and cattle numbers then decreased proportionally until a feasible solution was found. Pasture growth and animal performance remained as per the base scenario. This approach should deliver a (small) emission reduction mainly because young sheep (less than 1-year-old) currently have a 20% lower emission factor than cattle.

(ii) **Remove nitrogen fertiliser usage.** In this scenario, any nitrogen fertiliser was taken out of the model, and then both sheep and cattle numbers reduced proportionally until feed demand equated to feed supply. Animal performance levels remained as per the base scenario. This approach should lower both CH_4 and N_2O emissions due to lower dry matter intake and nitrogen content of the feed.

(iii) **Increase male/decrease female cattle.** This scenario varied slightly depending on the model, but essentially involved reducing female beef stock, particularly all non-replacement heifers or grazing heifers, and replacing them with bulls. Pasture growth and animal performance remained as per the base scenario. This scenario should deliver (small) emission reductions in the real world due to faster growth rates of bulls, but the main focus of the modelling analysis was on whether this would increase the profitability of farm systems. This would not reduce emissions in its own right but could increase flexibility to combine this approach with other mitigation approaches.

5.4.2 Results and discussion

Our results indicate that changing sheep/cattle or male/female ratios, with attendant adjustments to retain feasible farm systems, would result in negligible (typically 1% or less) changes in emissions and thus do not represent significant mitigation options. Our model results do indicate potentially significant implications for profitability (positive or negative depending on the specific farm system), suggesting that such changes would need to be explored in conjunction with specific farms and management changes as their implications for profitability will be highly context-specific.

Eliminating nitrogen fertiliser also results in very minor emission reductions (and similar reductions in profitability) of 1-3% for the North Island intensive and hill country farms and the South Island intensive farm; it was not applied to the South Island hill country farm model since no N fertiliser is applied routinely in this farm system. These results are consistent with the fact that N fertiliser in sheep & beef systems is generally used as a tactical option to respond to seasonal and market variability rather than as a continuous baseline input. Overall usage is generally limited, especially on hill country farms. As noted above (5.2), eliminating N inputs entirely could exacerbate challenges from seasonal feed supply/demand imbalances, control of shrubby weeds, and ability to maintain performance of both breeding and finishing stock.

6. Mitigation options for deer systems

Given time constraints for this report and the lack of readily available and tested models to relate deer production and feed intake to greenhouse gas emissions, we did not undertake independent modelling of mitigation options for deer systems but instead rely on work carried out previously in a separate report to MPI (Journeaux et al. 2016).

This report explored strategies broadly similar to those investigated in more detail for dairy and sheep & beef systems in this report, namely reducing stocking rates, eliminating N fertiliser, and retiring land to forestry or other land uses. There is insufficient statistical information available to develop an “average” model as per the dairy and sheep & beef models. With the main concentration of deer farming in New Zealand in the lower South Island, a “contrived” model based on this area was set up, along the lines of the previous 2012 MPI Deer Farm Monitoring model (MPI 2012).

Results have been updated to incorporate options for the ‘safe carbon’ or conservation sequestration potentials, and to include loss of soil carbon, for consistency with the treatment of those issues in the dairy and sheep & beef discussions. Numbers have also been updated to focus on the mitigation of biological GHG emissions only and ensure consistent treatment of farm areas (see Table 15).

We emphasise that our mitigation options have not considered options to increase productivity per animal, as an adequate animal model for this was not available. As the dairy and sheep & beef scenarios have shown, increasing productivity can be a potentially significant and cost-effective way of reducing GHG emissions, but we have insufficient evidence to speculate about the extent to which such approaches could be applied as mitigation strategy in the deer sector.

6.1 Reducing stocking rate

This scenario considers the potential to reduce emissions by reducing stocking rates by 10%. It did not focus strongly on increasing productivity at the same time (as we have in the dairy and sheep & beef scenarios), but rather using lower stocking rates to reduce input costs through eliminating bought-in supplements. Performance per animal was left essentially unchanged.

This scenario reduces biological GHG emissions by 11%, with almost all of the emission reduction coming from reduced stock numbers. Profitability was modelled to increase by 4%, based on elimination of costs for purchasing whole crop cereal, and cutting and selling surplus pasture as silage. The economic results are thus sensitive to the assumption of market prices for pasture silage.

Table 15. *Summary of key results for deer farms. For radiata forestry, the ‘safe carbon’ as well as the full 28-year sequestration potentials (light grey shaded rows) are given. For details, see text.*

	Biological Emissions Total	Net CO_2 change incl. carbon sequestration from forestry		Pastoral net profit	Enterprise net profit	
	kg CO_2 equivalent	Absolute emissions	Emissions Intensity	EBIT ($ pastoral total/yr)	EBIT (pastoral + forestry annuity)	Carbon Cost of Mitigation ($/t)
Base model (272 ha)	1,062,976			$140,080	$140,080	
Reduce stocking rate	945,744	-11%	-11%	$145,248	$145,248	-$44
Remove N fertiliser	1,057,536	-1%	0%	$140,624	$140,624	-$100
Radiata forest on marginal land (14 ha)	1,037,408	-8%	-3%	$126,616	$129,010	$129
(as above, using 28-yr seq. potential)	1,037,408	-37%	-35%	$126,616	$124,658	$39
Manuka forest on marginal land (14 ha)	1,037,408	-11%	-3%	$126,616	$131,036	$77

6.2 Removing N fertiliser

Eliminating N fertiliser use had a negligible effect on emissions (-1%) and essentially left profitability unchanged, consistent with the very limited use of N fertiliser in deer farms. In addition, when N fertiliser is applied, it is often more for tactical purposes to manage climate or market fluctuations, and thus removing N fertiliser as a rule could increase variability in economic returns and ability to achieve consistent pasture production.

6.3 Land-use change: forestry

This scenario retired 5% of the farm land to radiata or manuka forestry. Manuka has a higher growth rate and thus can sequester more carbon (although depending on its management and purpose, it may not meet the definition of a 'forest' in the New Zealand Emissions Trading Scheme), plus offers a higher annuity from honey production. It was assumed that the land placed into forestry was 'marginal' and hence produced only two thirds of the dry matter of the average farm; productivity of the remaining land was therefore increased by 2% to match the total dry matter production of the base farm. Stock numbers were adjusted to fit the revised total pasture supply, with supplementary feeds maintained at the original level.

This approach reduces net GHG emissions by 8% and 11% if the land is planted in radiata pine and manuka, respectively (assuming only the 'safe carbon' sequestration potential and including the loss of soil carbon). If radiata forest were planted for conservation purposes and the full carbon sequestration potential is used (including soil carbon loss), net emissions would be reduced by 37%.

These approaches were all found to reduce net profitability of the combined deer and forestry farm system. With the annuities given in Journeaux et al. (2016), profitability drops by 8% for the radiata forest and by 6% for the manuka forest, and by 11% for the conservation forest (if there is no return for the sequestered carbon). This translates into implied carbon costs of mitigation for radiata and manuka forests of \$129 and \$77/tCO_2e, respectively, if only the 'safe carbon' mitigation potential is used. If the full 28-year radiata sequestration potential is used with a negative annuity (as a proxy for a conservation forest), the implied carbon cost of mitigation would drop to \$39/tCO_2e.

These calculations suggest that retiring even marginal land from deer operations is generally not a cost-effective mitigation measure at near-term carbon prices. We also note that the higher stocking rate on the remaining pastoral land increases the risk arising from dry autumns or winters, as the feed demand and supply only just balances during the winter months. Dry conditions could therefore necessitate stock reductions or purchase of additional supplementary feeds, resulting in increased costs to maintain the farm system during some years.

7. Mitigation options for arable and horticulture systems

Biological GHG emissions from dedicated cropping (other than on-farm animal feed production) and horticulture constitute only a very minor fraction (less than 3%) of New Zealand's total biological emissions. As a result, no quantitative modelling of mitigation options was undertaken for this report as the overall mitigation potential will be small at national scale, regardless of the reductions that can be achieved for those emissions individually.

Here we summarise qualitative options and their co-benefits with other objectives, based on a detailed study commissioned in support of this report (Clothier et al. 2017: part 1).

7.1 Baseline emissions and emissions intensity

Emissions from horticulture systems in New Zealand arise mainly from the main commodities kiwifruit, viticulture and apples. For arable land use we considered mainly wheat and other grains, maize and ryegrass seed production. A lifecycle assessment shows that biological GHG emissions constitute only a small fraction of the total lifecycle emissions associated with production of these commodities, ranging from only 6% for wine grapes to 40% for arable systems (see Table 16).

Table 16. *Average total lifecycle and biological GHG emissions per hectare up to the farm gate, for main horticultural commodities and arable systems (Clothier et al. 2017: Table 14).*

Crop System	Average Total Greenhouse Gas Emissions (TGE) T CO_{2-e} ha^{-1}	IPCC Biological Greenhouse Gas Emissions (BGE) T CO_{2-e} ha^{-1}	Average Percentage of TGE as BGE %
Kiwifruit	5.5	1.03	19
Wine grapes	3.0	0.17	6
Apples	5.0	0.71	14
Arable [1]	2.4	0.95	40

[1] From Barber et al. (2011).

Most of the biological GHG emissions from these systems are associated with fertiliser use and, to a lesser extent, nitrogen deposition via prunings and leaf fall. [12] Note that emissions and associated N leaching vary widely in particular for different arable crops. Intensive vegetable production typically has much higher emissions and leaching rates.

7.2 Mitigation options

Most of the readily available and significant mitigation options for horticulture and arable systems relate to the on-farm energy consumption for farm transport, storage and buildings, as well as processing and post-farm gate transport and storage. Options to reduce biological GHG emissions generally are limited given the parsimonious use of nitrogen in horticulture, as excessive vigour is generally deleterious to production of premium fruit; mitigation options are somewhat greater for cropping given the heavier reliance on fertiliser but are still limited.

7.2.1 Kiwifruit

For kiwifruit, Clothier et al. (2017) report no significant measures to reduce N_2O emissions directly. Measures that could reduce such emissions indirectly are increasing the productivity of farm systems and turning prunings into biochar that is re-applied to orchards, but these measures are considered to reduce total (lifecycle) emissions of the orchard operations by less than 5%.

Potentially more significant emission savings could be achieved during the orchard establishment phase, where alternative approaches are estimated to reduce total GHGs by between 5 and 8%, but again most of those measures would not reduce biological GHG emissions. However, some measures could affect net biological emissions e.g. efforts to retain soil carbon and using prunings for biochar.

Information about changes in soil carbon under kiwifruit orchards is very limited. A single site comparison indicates that soil carbon does not decline with orchard age down to 0.5m of depth (which is greater than the standard depth of 0.3m commonly used to determine changes in topsoil carbon storage) and was comparable to the soil carbon content of pasture. This experiment also suggested that carbon content at much deeper levels (down to 9m) was significantly higher under the kiwifruit orchard than under pasture. If this reflects a systematic accumulation of soil carbon at deep levels under kiwifruit orchards, this could offset a significant fraction of total on-farm emissions, but both the depth of sampling required and the limited number of samples make such a conclusion highly speculative.

7.2.2 Viticulture

Based on the review in Clothier et al. (2017), there are no significant options to directly reduce biological GHG emissions from viticulture. Indirect measures consistent with the approach taken in

[12] For comparison, a Waikato/BOP dairy farm emits approximately 9.8t CO_2e/ha CH_4 (mostly from enteric fermentation), and 2.9 t CO_2e/ha N_2O from urine, dung and farm dairy effluent deposition and fertiliser use.

this report result from increasing the soil carbon content under vineyards through ensuring the vineyard floor is not left bare but covered by grass or another suitable crop. However, this may require broader management changes for pest and weed control. The modelled change in soil carbon through alternative vineyard floor covers would be sufficient to offset the entire emissions of biological GHGs from the vineyard, given that those are relatively small and only a minor component of the overall GHG footprint from a lifecycle perspective.

Vineyards are generally established in low-carbon soils, as increased vegetative vigour on more fertile soils presents problems for vine management. Even so, a small number of measurements to a limited depth (15cm) indicate that vineyards lose soil carbon over time, at a rate of about 36 tCO_2/ha over 15 years, or 2.4tCO_2e/ha/yr. On the other hand, the deeper roots of vines could result in carbon sequestration at greater depths. Those soil carbon changes, and mitigation options through grassing and mulching, would need to be considered for a full carbon accounting approach.

7.2.3 Apples

The review by Clothier et al. (2017) indicates that as for other horticultural products, the main mitigation options for GHG emissions associated with apple production relate to the consumption of fossil fuels associated with irrigation, storage and transport and on-farm operations.

Indirection mitigation options for biological GHG emissions would arise from efforts to increase the overall productivity and yield of orchards. However, it is unclear to what extent this would actually reduce *biological* GHG emissions per unit of product, or simply shift the balance between biological and CO_2 emissions.

Studies relating to soil carbon under apple orchards are inconclusive regarding feasible mitigation measures. A comparison of three orchards with different ages found no significant difference as a function of orchard age, but the limited number of data makes it difficult to draw general conclusions. Another study compared carbon content under tree rows and alleys in conventional and organic orchards, and found that carbon content was significantly lower under the tree row than the alley at depths of 5, 15 and 25cm for the conventional orchard, but only at 5cm for the organic orchard. This suggests that management of soil, including cover and management of orchard operations to manage soil compaction, can influence the net GHG balance.

Additional mitigation options arise during orchard renewal, as apple trees have a finite life of about 15 years. Alternative uses of woody biomass removed during the removal process, including for firewood or biochar, can make a small additional reduction to net orchard emissions.

7.2.4 Cropping

The total area of land currently planted in arable crops is estimated by Clothier et al. (2017) at about 500,000 ha. This includes cropping for animal feed on livestock farms, i.e. this area would not necessarily be classified as cropland in New Zealand's GHG emissions inventory. While emissions differ between crops, average lifecycle emissions from arable land are estimated by Clothier et al. (2017) at about 2.4 tCO_2e/ha, with biological GHG emissions constituting about 40% of this or 0.96 tCO_2e/ha. While lifecycle emissions per hectare are thus lower than those of horticultural enterprises, biological emissions are comparable to those from kiwifruit.

Given the greater intensity of nitrogen use in arable systems, some options exist to reduce biological GHG emissions. These can be summarised as:

- Optimising fertiliser usage to match actual N requirements
- Reduce soil compaction from trafficking as this can influence N_2O emissions
- Management of crop residues, and timing of ploughing and seeding of cover crops on pasture land to minimise soil carbon losses and N_2O emissions
- Minimising emissions from grazing of forage crops during wet conditions
- Optimising irrigation management

Approaches that reduce input costs, such as optimising fertiliser usage and irrigation management, can help increase farm profitability, but often rely on enhanced farmer skills and monitoring methods, and also can expose farmers to greater risks arising from climate and market variability.

Clothier et al. (2017) estimate that collectively, these approaches could reduce biological GHG emissions by perhaps 15-20% with limited or no negative impact on EBIT, although the impact on total emissions up to the farm gate (including use of fossil fuels) will still be moderate, given that biological emissions comprise only about 40% of total emissions.

Croplands typically have lower soil carbon storage than pasture or forest land, and soil carbon can continue to decline over time under certain management practices. Low- or no-till approaches as well as their timing, as well as management of crop residues, have been shown in studies internationally to have potential to enhance (or delay the decline of) soil carbon storage in croplands. Work is underway to test and quantify those options for cropping systems, soils and climates relevant to New Zealand.

8. Mitigation options through alternative land uses

Our modelling of dairy (Section 4) and sheep & beef (Section 5) farm systems indicates that retiring current livestock land to radiata forestry is not a cost-effective mitigation strategy for dairy farms under almost any realistic assumptions about milk payouts, carbon prices and forestry strategies for the next several decades. By contrast, it can be a cost-effective strategy for sheep & beef farms depending on the baseline profitability, forestry strategy and assumed carbon price.

However, radiata forestry is not the only alternative land-use conceivable. Planting other tree species would change the annuity and carbon sequestration rates but is unlikely to alter the broad picture fundamentally, and hence was not explored in detail for this report. An alternative approach to land-use change would be to switch to other, lower emitting land-uses. The main advantage of this approach is that some other land-uses with much lower emissions per hectare than dairy, sheep and beef systems tend to offer much higher profitability per hectare.

Estimated biological GHG emissions from horticulture and arable cropping as summarised in Clothier et al. (2017) range from 0.17 to just over 1 tCO_2e/ha, with kiwifruit and arable cropping having the highest biological GHG emissions per hectare.[13] By comparison, biological GHG emissions from dairy systems are on average over 12 tCO_2e/ha, and between 3.5 and 2.1 tCO_2e/ha for sheep & beef hill country farms in the North and South Island, respectively. This suggests that wide-spread land-use change from livestock towards arable and horticultural systems would *on average* result in significant reductions of biological GHG emissions for a given land area. However, given the much higher fraction of emissions related to fossil fuel consumption on horticultural and arable farms, overall emissions savings could be considerably less than the difference in biological GHG emissions would suggest.

A combination of livestock with some non-livestock enterprises could in principle retain an equally if not more profitable farm systems with lower absolute emissions. The overall emission reductions that can be achieved through such an approach will generally be less than if land is converted into forestry as most other land-uses do not offer the benefit of carbon sequestration; the reduction in biological emissions will simply reflect the difference in emissions per hectare between the original livestock land-use and the alternative land-use that replaces it. The outcome also depends on whether and by how much the livestock operation is intensified on the remaining pastoral land area, as this can influence overall profitability (see e.g. Sections 4.1 and 5.1). As shown above (Section 7), horticulture and arable cropping (in general) have lower emissions per hectare than dairy, sheep or

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[13] As noted earlier, arable cropping in particular shows a very wide range in emissions depending on the soil and crop grown. Some vegetable crops may offer little or no benefit in terms of biological GHG emissions even compared to dairy systems, and some have very high N leaching rates well in excess of dairy systems.

beef systems. The emissions savings are much smaller when land is converted from a sheep & beef operation into horticulture than if the conversion is from dairy land, and will depend on the specific crop and soil type.

To explore the biophysical and economic feasibility of such land-use changes, we commissioned a report (Clothier et al. 2017: part 2) to explore the overall potential, economic implications and barriers to strategic land-use change from livestock towards land uses with lower emissions per hectare (e.g. horticulture). These could either replace or be integrated with existing livestock production systems. Key findings from the report are summarised below. This assessment clearly only represents a first step towards exploring the options and barriers, and a more detailed analysis on a regional and enterprise specific basis will be needed if such an approach were to be considered seriously.

8.1 Estimated suitable land area and profitability

Clothier et al. (2017) estimate, using a simple mapping of land use suitability class, growing degree days, slope and frost free period, that the land area suitable for horticulture in New Zealand could be as large as 2 million hectares (see Figure 1), and an even greater area potentially suitable for arable cropping. By contrast, current land-use has roughly 55,000 ha in kiwifruit, grapes and apples, and another 121,000 ha in other fruits and vegetables. Out of the 2 million hectares of land identified as suitable for horticulture using this approach, more than 1.5 million is estimated to be currently under livestock production, mostly in dairy production.[14]

Established horticulture operations, based on summaries provided in Clothier et al. (2017), tend to have much higher profitability per hectare than livestock, ranging from $5,000 to $10,000/ha for vineyards, $15,000 to $20,000/ha for pipfruit, and in excess of $15,000/ha for kiwifruit depending on the variety. Note that these estimates are for established businesses only and imply a wide range of rates of return on investment, from 5% to over 20%.

At face value, the potentially suitable land area and profitability per hectare suggest that there is significant potential for horticulture to expand at the expense of livestock farming, and to do so with an attendant increase in net profitability. Note our assessment of the role of forestry on dairy land in Section 4.1.2 concluded that profitability of alternative land uses would have to be greater than $4,000-$8,000/ha to make a partial retirement of productive dairy land economically viable, which is well within the range of many of the horticultural enterprises considered, whereas that of arable farming generally falls well below this range.

14 The estimate of 1.5 million ha is based on evaluation of the New Zealand Land Cover Database showing high producing exotic grasslands in areas deemed suitable for horticulture. Note that the estimate of land suitability in his report is using only a finite set of simple criteria (for details see Clothier et al. 2017), which is unlikely to capture some highly relevant features. For example, this approach does not suggest any opportunities for avocado production on sandy soils in the Far North, nor for horticulture in Central Otago, yet there are significant plantings of grapes and summerfruit. This is because measures are taken to avoid the impacts of frosts in Central Otago, and the greater warmth of the summer months enables fruit maturation well within the stipulated frost-free period of 180 days in the simple mapping approach. On the other hand, periods of high humidity could pose problems not captured in this map, e.g. in the Waikato this would result in increased risks of crop failure or higher operational and infrastructure costs. The total area of land potentially suitable for horticulture should therefore be considered as indicative only for the national scale, and cannot be relied on to determine actual suitability at specific locations.

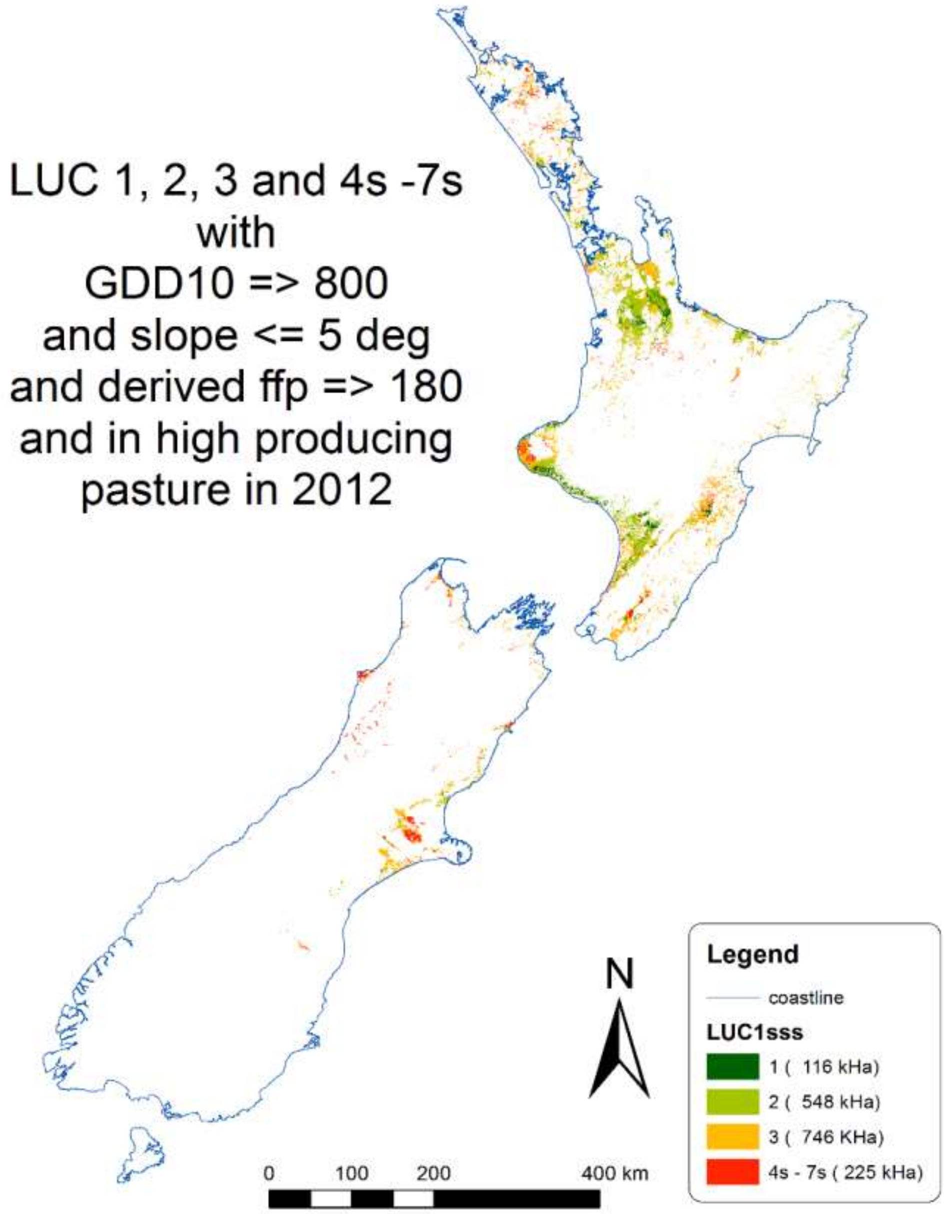

Figure 1. *Land Use Capability classes 1, 2, 3 and 4s–7s where criteria of Growing Degree Days, Slope and Frost Free Period are met and land is current high-producing exotic grassland. (Data reproduced with the permission of Landcare Research New Zealand Limited and NIWA). Source: Figure 29 from Clothier et al. (2017).*

8.2 Barriers to land-use change

The fact that livestock production nonetheless remains the dominant land use in most areas begs the question why this is the case. Clothier et al. (2017) discuss a range of potential reasons for this. These include but are not limited to:

- Infrastructure and capital investment costs
- Time lags between business decision-making, orchard establishment and full production
- Regional human resource and skill sets
- Access to water resources and allocation regimes
- Availability of and ability to access regional supply chains and supply chain infrastructure
- Fragmentation of land areas and critical mass for production and market access
- Experience and investors' appetite for risk

The rapid expansion of viticulture in some areas demonstrates that there is capacity for rapid growth if market signals and support systems come together. At the same time, New Zealand has considerable experience with horticulture failures and market contractions in some regions. However, Clothier et al. (2017) consider that such experiences were not primarily due to lack of biophysical suitability but due to complex issues including overinvestment and too rapid growth in some regions and industries and, in some instances, fruit sizes and timings that did not fit established markets and industry norms.

Another issue is that growing horticultural products on parts of livestock farms would pose significant management challenges and issues of scale. In many instances, it may be neither economic, feasible from a technical or managerial skill set, nor in the personal interest of livestock farmers, to run profitable horticultural enterprises at the same time as their pastoral enterprise. A key challenge therefore would be to develop sufficient off-farm infrastructure and management approaches that allow relatively small parcels embedded within livestock farms to act as a set of distributed orchards contributing to regional enterprises or cooperatives that can be managed with the required dedicated skills.

We emphasise that this is only a very preliminary and high-level exploration of the potential for and barriers to land-use change towards lower emitting activities. To arrive at a realistic appraisal of the potential for large-scale land-use change to contribute to significant reductions in New Zealand's biological GHG emissions more detailed regional biophysical and socio-economic assessments would need to be carried out. These would help develop a better understanding of the motivations and barriers for individuals, communities and industries, along with an assessment of their economic, social and environmental consequences.

References

AFRC (1993) Energy and Protein Requirements of Ruminants. Commonwealth Agricultural Bureaux, Wallingford, UK.

Allen MS (1996) Physical constraints on voluntary intake of forages by ruminants. Journal of Animal Science 74: 3063-3075

Beukes PC, Gregorini P, Romera AJ et al (2010) Improving production efficiency as a strategy to mitigate greenhouse gas emissions on pastoral dairy farms in New Zealand. Agriculture, Ecosystems & Environment 136(3–4): 358-365

Bryant J, Lopez-Villalobos N, Holmes C et al (2008) Development and evaluation of a pastoral simulation model that predicts dairy cattle performance based on animal genotype and environmental sensitivity information. Agricultural Systems 97: 13-25

Clothier B, Müller K, Hall A et al (2017) Futures for New Zealand's arable and horticultural industries in relation to their land area, productivity, profitability, greenhouse gas emissions and mitigations. A Plant & Food Research report prepared for the New Zealand Agricultural Greenhouse Gas Research Centre. New Zealand Agricultural Greenhouse Gas Research Centre, Palmerston North. pp66.

CSIRO (2007) Nutrient requirements of domesticated ruminants. CSIRO Publishing, Collingwood, Australia. pp270.

de Klein C et al. (2017) Initial review of the suitability of OVERSEER® Nutrient Budgets Model for farm scale greenhouse gas reporting. FINAL REPORT for Ministry for Primary Industries and the Biological Emissions Reference Group. Ministry for Primary Industries, Wellington. pp51.

Dowling L, Harrison D, Hock B (2017) Carbon sequestration under radiata pine forests in New Zealand. A report by Scion to the New Zealand Agricultural Greenhouse Gas Research Centre. New Zealand Agricultural Greenhouse Gas Research Centre, Palmerston North. pp21.

Dynes RA, Smeaton DC, Rhodes AP et al (2011) Modelling farm management scenarios that illustrate opportunities farmers have to reduce greenhouse gas emissions while maintaining profitability. Proceedings of the New Zealand Society of Animal Production 71: 167-171

Freer M, Moore AD, Donnelly JR (2006) The GRAZPLAN animal biology model for sheep and cattle and the GrazFeed decision support tool. CSIRO Plant Industry Technical Paper. CSIRO Publishing, Collingwood, Australia. pp46.

Jaffe A (2017) Barriers to Adoption of No-Cost Options for Mitigation of Agricultural Emissions: A Typology. Motu Note #24. Motu Economic and Public Policy Research, Wellington. pp9.

Journeaux PR, van Reenen E, Howarth S et al (2016) The Economic Impact of Greenhouse Gas Mitigation Strategies on the NZ Pastoral Agricultural Sector. Report to Ministry for Primary Industries. Ministry for Primary Industries, Wellington. pp110.

Kelliher F, Rollo M, Vibart R (2015) Desk-top review of GHG components of OVERSEER®. Report prepared for the New Zealand Agricultural Greenhouse Gas Research Centre, Palmerston North. pp31.

Ledgard SF, Basset-Mens C, Boyes M et al (2009) Carbon footprint measurement: Carbon footprint for a range of milk suppliers in New Zealand. Report to the Ministry of Agriculture and Fisheries. AgResearch, Hamliton, New Zealand. pp41.

Ledgard SF, Lieffering M, Coup D et al (2011) Carbon footprinting of New Zealand lamb from the perspective of an exporting nation. Animal Frontiers 1(1): 40-45

Ledgard SF, Falconer SJ (2015) Total greenhouse gas emissions from farm systems with increasing use of supplementary feeds across different regions of New Zealand. Final report to MPI. Ministry for Primary Industries, Wellington. pp70.

MPI (2012) Deer farm monitoring report. Ministry for Primary Industries, Wellington. pp6.

Nicol AM, Brookes IM (2007) The metabolisable energy requirements of grazing livestock. In: Rattray PV, Brooks IM, Nicol AM (eds) *Pasture and Supplements for Grazing Animals. Occasional Publication No. 14*. New Zealand Society of Animal Production, Hamilton, New Zealand

Parks JR (1982) A Theory of Feeding and Growth of Animals. Springer Verlag, Heidelberg, Germany,

Reisinger A, Clark H (2016) Modelling Agriculture's Contribution to New Zealand's Contribution to the Post-2020 Agreement. MPI Information Paper No: 2016/02. Ministry for Primary Industries, Wellington. pp55.

SCA (1990) Feeding standards for Australian Livestock: Ruminants. Standing Committee on Agriculture and Resource Management, Melbourne, Australia. pp266.

Smeaton DC, Cox T, Kerr S et al (2011) Relationships between Farm Productivity, Profitability, N Leaching and GHG Emissions: A Modelling Approach. Proceedings of the New Zealand Grassland Association 73. pp57–62.

Stroombergen A (2015) Emissions reduction options post-2020 - a general equilibrium analysis. Infometrics (released under the Official Information Act by the Ministry for the Environment), Wellington. pp34.

van der Weerden TJ, Laurenson S, Vogeler I et al (2017) Mitigating nitrous oxide and manure-derived methane emissions by removing cows in response to wet soil conditions. Agricultural Systems 156: 126-138.

Appendix I: Farm system characterisation and interventions

See separate spreadsheets attached to this report.

Appendix II: Carbon sequestration potentials and forestry annuities by region

Data for the 'safe carbon' sequestration potential are based on ETS look-up tables (MPI 2015). This represents the minimum carbon stored after harvesting of a first rotation and as the second rotation begins to grow, taking into account the decay of residual above- and below-ground wood assuming a 10-year linear decay. Full 28-year rotation sequestration potential is based on Dowling (2017). Dowling et al. (2017) data are spatially explicit and indicate different carbon sequestration for land that is currently under different livestock land-uses (dairy, sheep, beef, dry stock, and mixed sheep/beef), which could serve more detailed region and enterprise-specific modelling if required. In the summary table below, carbon sequestration has been averaged based on the current area-weighted land-use and for the average of two pruning regimes (one to grow knot-free timber, and another one to grow structural timber). For calculations in the body of the report, carbon sequestration on dairy land was used where forestry would replace land that is currently under dairy, and carbon sequestration rates on sheep and beef land categories was used where forestry would replace land that is currently under sheep or beef production.

Annuities are based on Dowling et al. (2017), reflecting averages for planting and pruning regimes designed to produce structural and knot-free timber over a 28-year rotation cycle. Profitability is given for the commercial 8% discount rate (5% discount rates are provided in Dowling et al. 2017). Annuities are based on commercial forestry returns only and exclude any payments for carbon sequestration. Annuities are highly sensitive to log prices. For this report, annuities were calculated based on log prices for 12 quarters taken from the AgriHQ log price database (July 2013 to July 2016, inclusive). Varying log prices by ±10% can result in about ±30% changes in the annuity (Journeaux et al. 2016).

Region	Auckland; Northland	Waikato	Bay of Plenty	Gisborne	Southern North Island (Hawke's Bay; Manawatu-Wanganui; Taranaki; Wellington)	Nelson; Marlborough; Tasman	Canterbury; Westland	Otago	Southland
Safe carbon sequestration level (tCO_2/ha; MPI 2015)	188	163	169	219	210	132	123	141	174
28-year full rotation potential (tCO_2/ha; Dowling et al. 2017)	1,01; 963	999	970	1,018	979; 995; 1,051; 918	906; 757; 836	737; 774	688	817
Annuity (8% disc. Rate, Dowling et al. 2017)	$328; $255	$295	$303	$267	$297, $330, $376, $254	$190, $70, $162	$97, $97	$96	$212
Annuity (5% disc. rate, Journeaux et al. 2016)	$180	$360	$360		$135 (Taranaki)		$81		$176
Annuity for radiata 28-yr conservation forest (5% disc. rate, Journeaux et al. 2016)	-$144	-$144	-$144	-$144	-$144	-$144	-$144	-$144	-$144