Manaaki Whenua
Landcare Research

Assessing the Nationwide Economic Impacts of Farm-Level Biological GHG Emission Mitigation Options

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Assessing the Nationwide Economic Impacts of Farm-Level Biological GHG Emission Mitigation Options

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Utkur Djanibekov, Tarek Soliman, Stephen Flood, and Suzie Greenhalgh

Manaaki Whenua – Landcare Research

Adolf Stroombergen

Infometrics

Reviewed by:	*Approved for release by:*
Oshadhi Samarasinghe Associate Economist Manaaki Whenua – Landcare Research	Suzie Greenhalgh Portfolio Leader – Supporting Business & Policy Manaaki Whenua – Landcare Research

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Executive Summary

The Biological Emissions Reference Group (BERG) was established in 2016. Its purpose is to build a robust and agreed evidence base on the opportunities that are available now, and in the future, to reduce on-farm emissions, and to assess the costs of, opportunities for, and barriers to doing so. As part of this evidence base BERG commissioned Manaaki Whenua – Landcare Research (MWLR) to explore the synergies and trade-offs between climate change on-farm mitigation options (hereafter 'mitigation options'), greenhouse gas (GHG) emissions, and agricultural profitability. In particular, BERG was interested in assessing the economic and environmental impacts of adopting mitigation options under four different GHG emission price scenarios (hereafter 'GHG prices') for biological GHG emissions from agriculture. These impacts were projected to 2030 and 2050 at regional and national levels.

Given that the focus of the analysis was to better understand the uptake of mitigation options in response to GHG prices and the corresponding economic implications, this analysis did not consider land-use change (except partial planting of forestry), the adoption of innovative technologies to increase agricultural productivity (except for one mitigation option in one of the analyses), or the abandonment of farming activity.

The main objectives of the analysis were to:

- determine the likely mitigation options and the possible adoption of these to reduce GHG emissions in the dairy and sheep & beef sectors
- outline barriers to the adoption of mitigation options
- estimate the subsequent economic impacts in terms of changes in agricultural productivity and profitability that result from the adoption of these mitigation options
- estimate the wider national impacts on gross domestic product (GDP), trade, and employment from pricing biological GHG emissions
- estimate the reduction in GHG emissions that would result from the adoption of mitigation options
- outline the likely environmental co-benefits or costs associated with pricing biological GHG emissions.

A mix of qualitative and quantitative approaches was used for the analysis. Figure S1 shows the different approaches used and the links between them. Workshops were convened with the BERG members to agree on (1) the farm-level data and farm systems to be used in the analysis and (2) the mitigation options to include in the analysis, and also to (3) explore why different mitigation options might or might not be adopted.

Two analyses were undertaken for the agricultural sector, such that Analysis II included an additional mitigation option to Analysis I for the dairy sector, which involved reducing cow numbers while increasing milk production per cow. For the sheep & beef sector the same mitigation options were available in both analyses. The impacts of different GHG prices on the adoption of mitigation options and the subsequent profits (i.e. earnings before interest and taxes) and GHG emissions were estimated using MWLR's New Zealand

Forestry and Agricultural Regional Model (NZFARM). The wider economic consequences of pricing biological GHG emissions were then estimated using Infometrics's general equilibrium model (ESSAM). The costs and benefits not captured by the economic modelling approaches were described using a qualitative ecosystem services assessment.

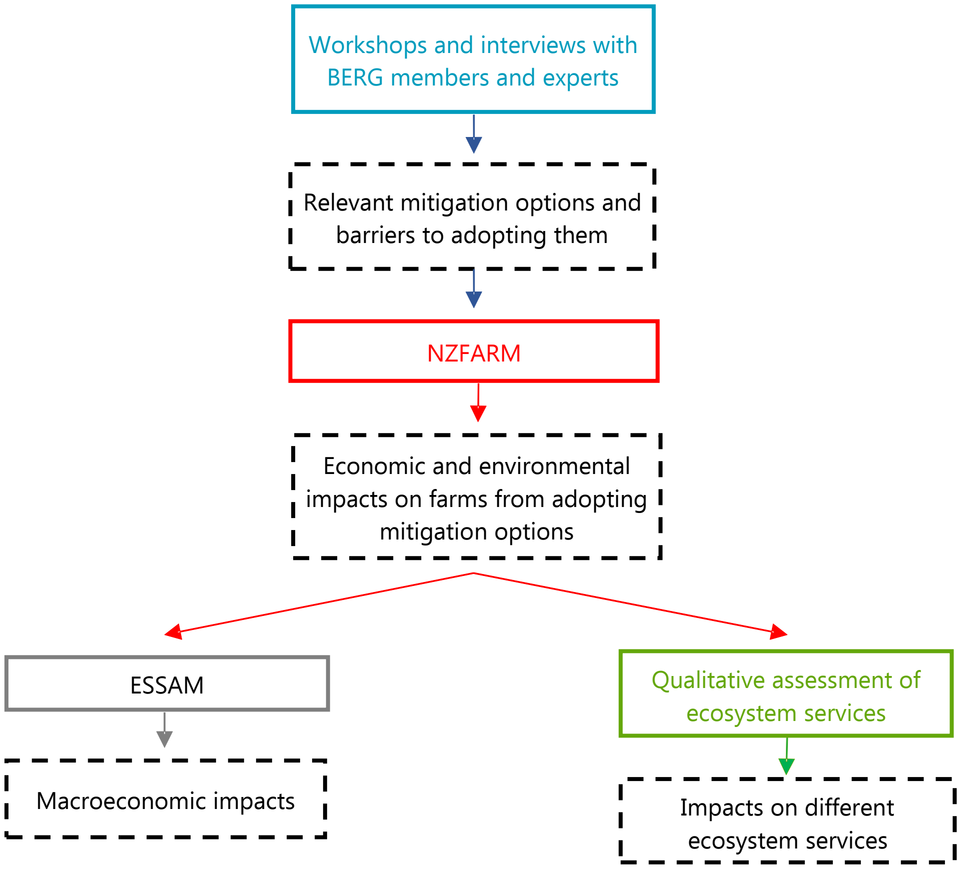

Figure S 1: Flow of the study showing the use of qualitative and quantitative approaches.

Mitigation options and their barriers

In this report we considered a range of mitigation options that can reduce GHG emissions in the dairy and sheep & beef sectors. These mitigations options are currently available technologies and practices. The mitigation options involve changes in farm management practices, reductions in land-use intensity, and partial land-use change through the planting of forestry.

The following mitigation options were modelled for the dairy sector, based on discussions with DairyNZ:

- Option 1: Output approach to reducing GHG emissions, which includes a combination of input use reductions[1]

[1] Includes a targeted percentage reduction from base GHG emissions. This option combines reductions in fertilser rate, supplementary feed and cow numbers.

- Option 2: Reduction in fertiliser use
- Option 3: Change in supplementary feed
- Option 4: Reduction in cow numbers while maintaining milk production per cow
- Option 5: Once-a-day milking
- Option 6: Planting forestry
- Option 7: Reduction in cow numbers while increasing milk production per cow (only modelled in Analysis II).

The following mitigation options were modelled for the sheep & beef sector based on discussion with Beef + Lamb New Zealand:

- Option 1: Reduction in stocking rate – maintain production/area farmed
- Option 2: Replace breeding cows with surplus dairy animals
- Option 3: Planting forestry – maintain production.

For the most part we did not include mitigation options that influence productivity in the dairy and sheep & beef sectors. The mitigation options used in our analysis were based on discussions with BERG members, who identified the most relevant mitigation options for their sectors to reduce GHG emissions. We did, however, at the request of BERG members, later in the process undertake an analysis (Analysis II) that included a mitigation option that involved increasing dairy sector productivity (i.e. Option 7).

The circumstances of individual farmers will influence whether or not mitigation options are taken up. This was particularly so for sheep & beef farmers, where there is a heterogeneity in land characteristics as well as farmers' behaviours. The key barriers identified internationally, and confirmed by sector experts, highlighted that the actual or perceived effects of GHG mitigation actions on farm performance and profitability was the greatest influence on farmer adoption.

The most common reasons for farmers to adopt mitigation options to improve water quality – another environmental constraint facing farmers – were stewardship, having the skills, and the perceived benefits from adopting a mitigation option. These are also likely to be adequate proxies for why farmers would adopt mitigation options to reduce GHG emissions. Therefore, promoting the adoption of mitigation options to reduce GHG emissions, especially those likely to be effective for the different sectors, will require approaches/strategies to address these barriers.

Agricultural sector impacts of pricing GHG emissions

The NZFARM model was used to estimate the impacts of the uptake of mitigation options on the agricultural sector under different GHG prices (Table S1). To better understand the adoption rate of mitigation options and the effects of mitigation options under different GHG prices, we do not include land-use change, except the partial planting of forestry on dairy and sheep & beef land. Also, if a farm becomes unprofitable, we assume that farmers continue to operate and do not shift to another land use or abandon farming. This is not uncommon in the agricultural sector. Farmers do exit the agricultural sector, however, after long periods of unprofitability. We also do not account for any challenges arising from managing the disease *Mycoplasma bovis* that may restrict the movement of cattle in New Zealand, at least in the short term.

The key elements of the modelling for these analyses were as follows.

- The baseline year was 2012.
- The years 2030 and 2050, the reference cases, were the two points at which the impacts were assessed.
- We considered 27 dairy farms, which include five dairy systems, and this information was obtained from DairyNZ. For the sheep & beef sector we considered six sheep & beef systems and relied on information from Beef + Lamb New Zealand and Reisinger et al. (2017)
- Four GHG price scenarios were used to assess the economic impacts on the agricultural sector of pricing biological GHG emissions. In all GHG price scenarios, the price for carbon (C) sequestration payments was the same. C sequestration from forestry is already rewarded under the Emissions Trading Scheme (ETS), so these payments were used to derive land-use areas for the 2030 and 2050 reference cases (see Dorner et al. 2018). As a result, the C sequestration payment and the GHG prices differ (see Table S1). This allows us to specifically capture the impacts of different GHG prices.

Table S 1: Description of GHG prices

Year	C sequestration reward $/tCO$_2$e	GHG price scenarios[2]			
		GHG1 $/tCO$_2$e	GHG2 $/tCO$_2$e	GHG3 $/tCO$_2$e	GHG4 $/tCO$_2$e
2012	$5.00	$15.00	$25.00	$50.00	$100.00
2030	$26.26	$20.25	$33.75	$67.5	$135.00
2050	$37.35	$28.73	$47.88	$95.77	$191.54

We conducted two analyses, which involved different sets of mitigation options for the dairy sector:

- Analysis I, which included mitigation options 1–6 for the dairy sector and options 1–3 for the sheep & beef sector
- Analysis II, which included mitigation options 1–7 for the dairy sector and options 1–3 for the sheep & beef sector, but also included a mitigation option that reduces dairy cow numbers while increasing milk production per cow (i.e. increased dairy sector productivity).

These analyses reflect a realistic set of mitigation options (Analysis I) available to the dairy sector, and a more optimistic set of mitigation options where productivity improvements are available and would be widespread across the dairy sector (Analysis II) .

[2] We assume that C sequestration rewards to the farmer and GHG prices increase over time based on the expected increase in interest rate (see Dorner et al. 2018, and section 2.1).

Dairy sector

Analysis I shows that the dairy sector will adopt a range of different mitigation options to reduce the financial impacts of pricing biological GHG emissions to maximise profits. For example, in response to low GHG prices there is uptake of the output approach, changing supplementary feed, once-a-day milking, and partial planting of forestry. Under low GHG prices, cheaper but less effective GHG reducing mitigation options are adopted. Thus, low GHG prices do not incentivise dairy farmers to adopt mitigation options that result in greater reductions in GHG emissions and decrease profit.

Under the low GHG prices in both 2030 and 2050, the region that allocates most of its area to no mitigation options is Canterbury, while regions that entirely allocate their land for mitigation options are the West Coast, Tasman, Nelson, and Marlborough, where the output approach and planting forestry mitigations are adopted (Tables A1 and A3 in Supplementary Material I).

As GHG prices increase, the adoption of once-a-day milking declines and instead reducing fertiliser use and reducing cow numbers with no change in milk production per cow are taken up, alongside greater uptake of the output approach. For instance, in 2030 with the low GHG price (GHG1), the once-a-day milking option has been adopted on half of the land of the Northland and Auckland regions, but in 2050 with the highest GHG price (GHG4) this mitigation option is not practised, and instead reduction in fertiliser use and stocking rate options are mostly adopted (Tables A1 and A4 in Supplementary Material I). These mitigation options are higher-cost options in terms of impacts on profitablity but do result in larger reductions in GHG emissions. At the highest GHG price (GHG4), reducing fertiliser use and reducing cow numbers, while maintaining milk production per cow, have a smaller impact on profitability than other mitigation options.

There were also marked differences between the adoption of mitigation options by farm system and region, and this information is showen in detail in Supplementary Materials I and II.

In Analysis II, the additional mitigation option – reduction in cow numbers with an increase in milk production per cow – is the predominant mitigation option taken up by the dairy sector. This mitigation option reduces GHG emissions and has a smaller impact on profits compared to other options. There is also some adoption of the output approach, once-a-day milking, and the partial planting of forestry. For instance, in 2050 under the highest GHG price (GHG4), the dairy sector in Gisborne, Hawke’s Bay, Manawatu–Wanganui, Taranaki, and Wellington allocate one-fifth of their land to the output approach, and the dairy sector in Marlborough, Nelson, Tasman, and the West Coast adopt the output approach on 60% of their land, while the remaining land areas are entirely allocated to the reduction in cow numbers with an increase in milk production per cow option (Table B4 in Supplementary Material II).

Such adoption trends are due to the fact that these mitigation options are more profitable in some regions for certain dairy systems than reducing cow numbers with an increase in milk production per cow, or any of the other mitigation options when biological emissions are priced.

GHG emissions from the dairy sector in Analysis I are reduced between 1% and 9% in 2030 and between 2% and 15% in 2050 (Table S2(a)). In contrast, the reduction in GHG emissions in Analysis II is larger, at 18–19% in 2030 and 2050 (Table S2(b)). This larger reduction is due to the greater adoption of mitigation options overall, in particular the mitigation option that reduces cow numbers while increasing milk production per cow. This option has the largest profit among all mitigations options and reduces GHG emissions more than some of the other options considered in Analysis I and Analysis II.

The impact on dairy sector profits is also lower in Analysis II, where profits decrease by between 7% and 59% in 2030 and between 11% and 84% in 2050. For example, under the GHG1 in 2030, the region that generates the largest dairy profits is Waikato, followed by Canterbury, and in both regions dairy land users entirely allocate their land to the option involving a reduction in cow numbers and an increase in milk production per cow (Table B4 in Supplementary Material II). In 2050, with the highest GHG price (GHG4), Waikato still generates the largest profits among the regions, while Canterbury incurs the highest losses, even considering that both regions practise only the option to reduce cow numbers and increase milk production per cow. This is because dairy in Canterbury has high GHG emissions and not the largest profits per hectare, and so dairy in this region has substantial losses resulting from GHG prices.

In Analysis I, profits decrease between 9% and 70% in 2030 and between 14% and 98% in 2050. This difference in profitability is again driven by the large uptake of the mitigation option that reduces cow numbers while increasing milk production per cow. While not modelled in this analysis, dairy farmers may consider other management changes when profits decrease significantly. This may involve totally changing land use (e.g. shifting from dairy to horticultural farming), or adopting different technological options that boost farm productivity to avoid the financial losses associated with high GHG prices.

Our analysis does, however, highlight the implications of pricing biological emissions given the suite of mitigation options currently available to the dairy and sheep & beef sectors. The regional results show the dairy systems and regions that are likely to be most affected financially when faced with pricing biological GHG emissions if there is no ability to completely change land use, or there is only a limited range of mitigation options (see Supplementary Material I and II).

Table S 2: Summary results for dairy showing relative change under different GHG prices with respect to the reference case in Analysis I (a) and in Analysis II (b)

(a)

Scenario	Profits, in $ million	GHG emissions, in 1,000 tCO_2-e
	Simulation results for 2030	
Reference case	2,940	16,279
GHG1 ($20.25/$tCO_2$-e)	–9%	–1%
GHG2 ($33.75/$tCO_2$-e)	–17%	–2%
GHG3 ($67.5/$tCO_2$-e)	–35%	–3%
GHG4 ($135/$tCO_2$-e)	–70%	–9%
	Simulation results for 2050	
Reference case	2,940	16,279
GHG1 ($28.73/$tCO_2$-e)	–14%	–2%
GHG2 ($47.88/$tCO_2$-e)	–24%	–2%
GHG3 ($95.77/$tCO_2$-e)	–50%	–5%
GHG4 ($191.54/$tCO_2$-e)	–98%	–15%

(b)

Scenario	Profit, in $ million	GHG emissions, in 1,000 tCO_2-e
	Simulation results for 2030	
Reference case	2,940	16,279
GHG1 ($20.25/$tCO_2$-e)	–7%	–18%
GHG2 ($33.75/$tCO_2$-e)	–13%	–18%
GHG3 ($67.5/$tCO_2$-e)	–28%	–18%
GHG4 ($135/$tCO_2$-e)	–59%	–19%
	Simulation results for 2050	
Reference case	2,940	16,279
GHG1 ($28.73/$tCO_2$-e)	–11%	–18%
GHG2 ($47.88/$tCO_2$-e)	–20%	–18%
GHG3 ($95.77/$tCO_2$-e)	–41%	–19%
GHG4 ($191.54/$tCO_2$-e)	–84%	–19%

Sheep & beef sector

The same mitigation options for the sheep & beef sector were considered for Analysis I and Analysis II. Therefore, the impacts of pricing biological GHG emissions were the same for the sheep & beef sector in both analyses. All available mitigation options were adopted to some degree by this sector. Planting forestry was the most common, followed by reducing stocking rates (while maintaining production) and removing breeding cows. Although removing breeding cows is more profitable than other options, there is little opportunity for large increases in this mitigation option because the removal of breeding cows has already happened, where possible. Based on discussions with Beef + Lamb New Zealand, we capped the additional uptake of this mitigation option at 5% of the suitable sheep & beef land.

With the highest GHG price (GHG4) in 2050, none of the regions use no mitigation option, and all of the regions mostly adopt planting forestry on marginal lands and on 30% of sheep & beef land, with the possibility of maintaining production (Table A16 in Supplementary Material I).

The corresponding reduction in GHG emissions from the sheep & beef sector is between 21% and 29% in 2030 and 20% to 34% in 2050, depending on the GHG price (Table S3). When comparing the reduction in GHG emissions under the GHG4 price scenario with the GHG1 scenario in 2050, we found that the largest relative decrease in emissions occur for Nelson (decrease of 39%) and Marlborough (decrease of 37%), due to substantially increased planted forestry area and not using the 'no mitigation' option (Tables A23 and A24 in Supplementary Material I, and Tables B23 and B24 in Supplementary Material II).

Sheep & beef sector profits decreased between 9% and 89% in 2030 and between 15% and 123% in 2050 as GHG prices increased. The largest relative profit decrease occurs for the sheep & beef sector in Auckland and Northland, while the lowest relative profit decrease for this sector is in Gisborne and Hawke's Bay (Tables A17–A20 in Supplementary Material I, and Tables B17–B20 in Supplementary Material II). Similar to the dairy sector, the reduction in profits as GHG prices increase comes from the low profitability (or even losses) of some types of sheep & beef farm systems in certain regions (see Supplementary Materials I and II). While farmers may change land uses or exit the industry with prolonged periods of negative or low profits, this option is not available in this analysis.

Table S 3: Summary results for sheep & beef showing relative change under different GHG prices with respect to the reference case in Analysis I and Analysis II

Scenario	Profit, in $ million	GHG emissions, 1,000 tCO_2-e
	Simulation results for 2030	
Reference case	2,577	23,072
GHG1 ($20.25/$tCO_2$-e)	–9%	–21%
GHG2 ($33.75/$tCO_2$-e)	–19%	–21%
GHG3 ($67.5/$tCO_2$-e)	–43%	–21%
GHG4 ($135/$tCO_2$-e)	–89%	–29%
	Simulation results for 2050	
Reference case	2,313	20,635
GHG1 ($28.73/$tCO_2$-e)	-15%	–20%
GHG2 ($47.88/$tCO_2$-e)	–29%	–20%
GHG3 ($95.77/$tCO_2$-e)	–63%	–22%
GHG4 ($191.54/$tCO_2$-e)	–123%	–34%

NB. the same mitigation options were available to the sheep & beef sector in Analysis I and Analysis II. Therefore the results for both analyses are the same for the sheep & beef sector.

Across the agricultural sector, GHG emissions reduced between 12% and 20% in 2030 and between 12% and 25% in 2050 in Analysis I, depending on GHG prices (see Table 10). The corresponding reduction in profits from the pricing of biological GHG emissions was 6% to 47% in 2030 and 8% to 61% in 2050. The reduction in GHG emissions in Analysis II is greater than in Analysis I and is driven by the greater reduction in the dairy sector (see Table 21 and Table 26). Emissions are reduced by 19% to 24% in 2030 and by 19% to 26% in 2050, depending on GHG prices. The impacts on profits are also moderated by the additional mitigation option for dairy in Analysis II. In Analysis II, profits decrease by 5% to 44% in 2030 and by 7% to 57% in 2050, depending on the GHG price.

Our analysis shows marked decreases in profits when the available mitigation options do not increase the profitability of the livestock sectors. We could expect that farmers within the dairy and sheep & beef sectors would be incentivised to change land use rather than adopt mitigation options that do not increase their financial viability. Therefore, given that skills are a key barrier to the adoption of new mitigation options, upskilling the agricultural sector to assist with the transition to other agricultural industries or other sector is likely to be an important part of implementing any pricing of biological GHG emissions. Supplementary Materials I and II provide some additional information on the regions and farm systems that are likely to face the greatest challenge in staying financially viable when biological GHG emissions are priced.

Wider economic impacts of pricing agricultural GHG emissions

The NZFARM results for Analysis I and Analysis II were then used as input data to simulate the macroeconomic effects of pricing biological GHG emissions using the ESSAM model. The macroeconomic analysis showed that under the lowest GHG price scenario, minor macroeconomic effects will be felt. GDP is expected to be reduced by only 0.1%, but the slight lift in the terms of trade is enough to prevent a reduction in New Zealand's real gross national disposable income (RGNDI) and private consumption. Although the exogenous change in GHG emissions is 1.7 Mt, the price on emissions impairs the competitiveness of agricultural exports, leading to a reduction in agricultural output, which in turn lowers agricultural emissions by 2.6 Mt.

The highest GHG price scenario has larger impacts. Exports and GDP decline, enabling resources to flow instead into private consumption. This means the macroeconomic impacts of extending an existing price on emissions to apply to biological GHG emissions, and securing the associated reduction in on-farm emissions, can be negative (using GDP as the metric) or positive (using RGNDI as the metric).

It should be noted that this analysis extends to 2050. For such a long-term analysis it can be relevant to consider the uncertainty associated with future decisions, as commodity outputs (as a result of climate change) and prices (as a result of price fluctuations), as well as policies, might change and vary over the years.

Wider ecosystem service costs and benefits

We used the qualitative approach to assess the effect on ecosystem services of pricing GHG emissions. Ecosystem services are the benefits that nature provides. We used an ecosystem services approach to look at the wider potential costs and benefits of pricing biological GHG emissions. This approach allows us to assess the impacts of GHG prices that are not quantified by the economic modelling.

We expect that in many instances the impact on regulating services such as regulation of air quality, climate, water yield, water purification and waste, erosion, disease, biological control, and pollination will be positive, as the mitigation options tend to improve the flow of such services. The exception is any negative effect on air quality maintenance services of increased pollen production from the additional forest area. Water yield is also expected to decrease with more forested areas, which will negatively affect water regulation services. This can be considered a positive effect if the decreased water yield reduces flood events, or negative if river flows are used for irrigation, or the lower flows affect the ecological health of a freshwater system. Food and fibre production are directly affected by pricing GHG emissions, and the impact tends to be negative due to the estimated decrease in overall livestock production levels resulting from the adoption of mitigation options.

There are also a number of indirect impacts, where the change in one ecosystem service affects another ecosystem service. For instance, some of the expected change in wild foods and recreation is related to changes in climate, water purification, water regulation, and erosion control services. Given that these regulating services are expected to improve, then wild foods and recreation benefits are also likely to increase. Some impacts may also be positive or negative depending on a person’s preference and/or the location of some of these changes. For instance, the impact on aesthetic values (e.g. views) from increased forestry will differ based on the location of new forested areas, the mix of tree species, and how the community/individuals regard the aesthetic value of forests.

1 Introduction

The Biological Emissions Reference Group (BERG) was established in 2016. The purpose of BERG is to build a robust and agreed evidence base on the opportunities that are available now, and in the future, to reduce on-farm emissions, and to assess the costs of, opportunities for, and barriers to doing so.

BERG commissioned Manaaki Whenua – Landcare Research (MWLR) to explore the synergies and trade-offs between climate change on-farm mitigation options (hereafter 'mitigation options'), greenhouse gas (GHG) emissions, and agricultural profitability. In particular, BERG was interested in assessing the economic and environmental impacts of adopting mitigation options under four different GHG emission price scenarios (hereafter 'GHG prices') for biological GHG emissions from agriculture. These impacts were projected to 2030 and 2050 at regional and national levels. In addition, we discuss barriers to the uptake of the mitigation options and the likely co-benefits or costs of adopting the proposed mitigation options.

The objectives of the analyses are to:

- determine the likely mitigations and the possible adoption of these to reduce GHG emissions by the dairy and sheep & beef sectors
- outline barriers to the adoption of mitigation options
- estimate the subsequent economic impacts in terms of changes in agricultural productivity and profitability that result from the adoption of these mitigation options
- estimate the wider national impacts on gross domestic product (GDP), trade, and employment of pricing agricultural GHG emissions
- estimate the reduction in GHG emissions that will result from the adoption of mitigation options
- outline the likely environmental co-benefits or costs associated with the pricing of biological GHG emissions from agriculture.

To achieve these goals, we have utilised a mix of qualitative and quantitative modelling approaches (Figure 1). The impacts on dairy farms and sheep & beef farms from adopting on-farm management practices in response to different GHG pricing scenarios were estimated using an agri-environmental economic optimisation model – the New Zealand Forestry and Agricultural Regional Model (NZFARM; Daigneault et al. 2017). The resulting changes in production were then used in a general equilibrium model – the Energy Substitution, Social Accounting Matrix (ESSAM), developed by Infometrics (Stroombergen 2010, 2011, 2012, 2015) – to estimate the wider economic impacts. The costs and benefits not captured by the economic modelling approaches were described using a qualitative ecosystem services approach.

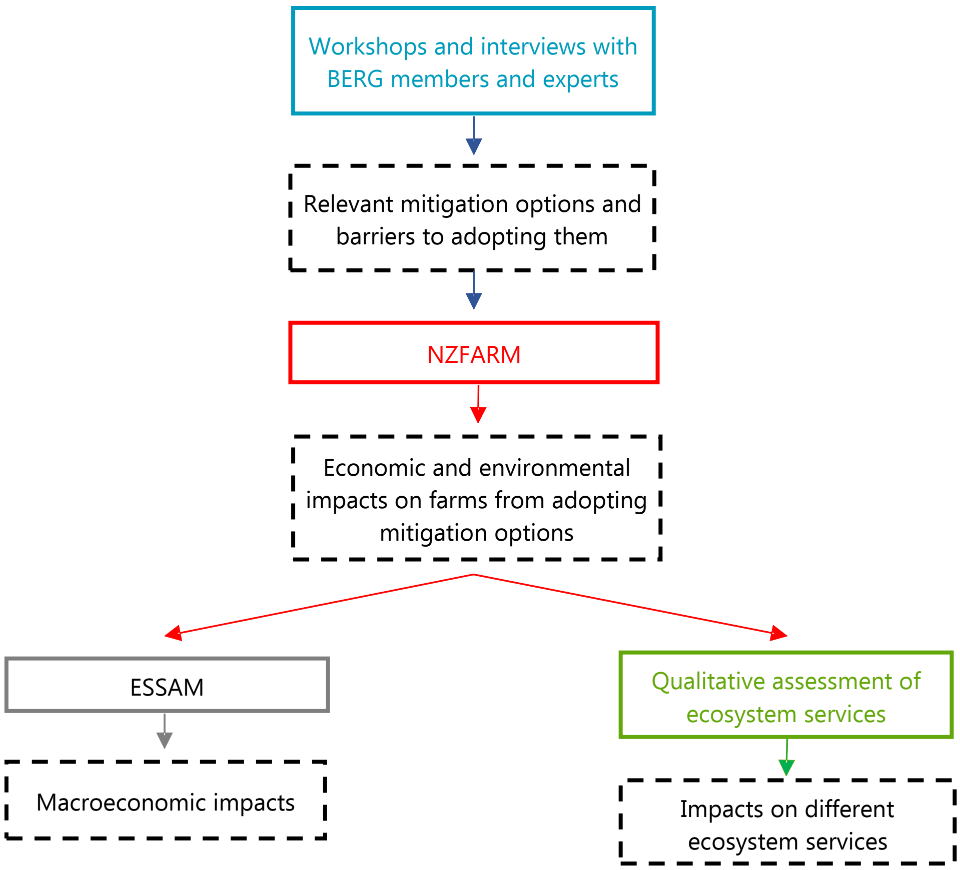

Figure 1: Qualitative and quantitative approaches used for the analysis.

2 Methods

Our analysis employs several qualitative and quantitative approaches to assess the nationwide impacts of implementing GHG prices and adopting mitigation options in New Zealand.

Workshops were convened with the BERG members to agree on (1) the farm-level data and farm systems to be used in the analysis and (2) mitigation options to include in the analysis, and (3) to explore why different mitigation options might or might not be adopted. Additional follow-up discussions, sourcing of existing information, and/or modelling were undertaken with DairyNZ, Beef + Lamb New Zealand, and Horticulture New Zealand to obtain the agreed farm systems' information, and for the dairy and sheep & beef sectors to provide or agree on the impacts of the mitigation options.

A qualitative assessment was undertaken to ascertain barriers to adopting mitigation options for the dairy and sheep & beef sectors (see section 3). This assessment was based on a review of the literature and consultation with industry experts from DairyNZ and Beef + Lamb New Zealand.

Two sets of economic analyses were undertaken for this report. The difference between the two analyses was that the second analysis, Analysis II, included an additional mitigation option to those covered in Analysis I (see Table 5). Analysis II was added at the request of the BERG members to ascertain the economic and GHG impacts of a mitigation option that reduced GHG emissions while increasing the profitability of the dairy sector.

The economic modelling was undertaken using MWLR's NZFARM model to simulate the impacts of adopting mitigation options on the dairy and sheep & beef sectors under different GHG prices. The mitigation options and assumptions considered are outlined in sections 2.2 and 2.3. The land-use areas in the 2030 and 2050 reference cases (see Table 1) are used in NZFARM to estimate the area of each mitigation option that is adopted under each GHG price. NZFARM estimates agricultural profits, agricultural production, and GHG emissions. The results for Analysis I are given in section 4, while Analysis II results can be found in section 5. A detailed description of the NZFARM model is included in Appendix 1.

The results from NZFARM are used as inputs into the ESSAM model to estimate the wider economic impacts of pricing GHG emissions. The ESSAM model estimates the spill-over effects of the changes in response to pricing biological GHG emissions from agriculture on other related sectors in the economy, as well as on national indicators such as GDP, employment, and trade. The ESSAM results are also found in section 4 for Analysis I and in section 5 for Analysis II. A more detailed description of the ESSAM model is included in Appendix 2.

An assessment of the wider effects of pricing biological GHG emissions on the environment and society was undertaken using an ecosystem services framework. This involved a qualitative assessment of the effects on the range of ecosystem services using a rapid ecosystem service assessment. The approach used for this assessment and the results are outlined in section 6.

2.1 Scenarios

2.1.1 Baseline and reference cases

The modelling periods for the analyses are 2030 and 2050. In NZFARM we include the following land uses: dairy, sheep & beef, deer, other pasture, arable, forestry, fruits, pipfruit, vegetables, viticulture, native, and other. Dairy includes five systems that are distributed across New Zealand (see Appendix 4). For the sheep & beef sector, we consider six systems/types that are classified according to topology and management practices. In ESSAM, we consider dairy, sheep & beef, horticulture, other farming, and forestry land uses.

The baseline, in terms of initial land-use area for the analysis, is 2012. The 2012 land-use areas were derived from Agribase[3] and the NZ Land Cover Database.[4] The 2030 and 2050 reference cases, or 'business as usual patterns' of land use (i.e. assuming no changes to current land-use trends and drivers), were generated using Motu's Land Use in Rural New

[3] http://www.asurequality.com/capturing-information-technology-across-the-food-supply-chain/agribasedatabase-of-new-zealand-rural-properties.cfm

[4] https://www.data.govt.nz/case-studies/land-cover-database/

Zealand model (LURNZ). The reference case accounted for carbon (C) sequestration rewards for forestry that increased over time at the rate of interest. This resulted in forestry profits and area increasing over time (see below for an explanation of the assumption for deriving the C sequestration reward). Other emissions that are already priced under the Emissions Trading Scheme (ETS), such as for energy, are also accounted for in the reference case. There is no pricing of biological GHG emissions though. The reference cases are described by Dorner et al. (2018), who used the same 2012 baseline land use as our analysis to derive the 2030 and 2050 reference cases. Table 1 outlines the 2012 baseline land-use areas and corresponding profits, and GHG emissions.

This analysis focuses on reducing GHG emissions and does not account for any regional policies that have been or are being developed in response to the National Policy Statement for Freshwater Management (NPSFM) or other similar environmental policies. The effects of the NPSFM on GHG emissions were assessed by Shepherd et al. (2016). There was also no uptake of GHG mitigation options considered in the baseline and reference cases.

In the reference cases, we assume that C sequestration rewards or payments to the farmer increase over time based on the expected increase in interest rate. This is consistent with a complementary report by Dorner et al. (2018), which focused on the impact of GHG reduction targets on land-use change. The price for C sequestration in forestry starts at \$5/tCO_2-e in 2012 and increases annually by the real interest rate. Using the Treasury 2017 rates, for the period 2017 to 2021 we use the nominal interest rate, which is the 90-day bank bill rate. The 2021 interest rate is maintained for the remaining time periods. To derive the real interest rates, we use the nominal 90-day bank bill rate minus the consumer price index (CPI) projections, which are also constant after 2021. This gives a real interest rate of 1.8% from 2021 onwards. We do not consider GHG prices in the baseline and reference cases (for scenario descriptions, see section 2.1.2).

According to Dorner et al. (2018), the reference case for 2030 shows that sheep & beef farming cover the largest land area (29%), followed by forestry (10%), and dairy (8.8%). The reference case for 2050 shows that these enterprise areas have changed slightly: 27% is allocated to sheep & beef, 13% to forestry, and 8.8% to dairy. The area in sheep & beef has reduced and shifted to forestry. In addition, the area of native land uses (including scrub) has reduced over this period as some scrub area is converted to forestry. The increase in forestry is mainly driven by the more favourable conditions for forestry with the ETS payment for C sequestration.

The 2030 reference case shows that the dairy sector earns the highest share of profits at 33%, followed by the sheep & beef, forestry, and viticulture sectors, which represent 27%, 17%, and 7%, respectively, of the total agricultural profit, estimated at c. $9.3 billion. In the 2050 reference case, the highest share of profits is earned by dairy (31%), followed by sheep & beef (25%), and forestry (20%).

The 2030 reference case GHG emissions show that the sheep & beef and dairy sectors have the largest contribution to New Zealand’s total biological emissions, representing 56% and 39%, respectively. The same pattern continues in 2050, where the sheep & beef and dairy sectors represent 53% and 42%, respectively, of total GHG emissions (Table 1).

To better capture the impacts of GHG prices and the uptake of mitigation options, no productivity increases were considered (except for one mitigation option in Analysis II).

Table 1. Land use, profit, and GHG emissions data for 2012 baseline, and 2030 and 2050 reference cases

Land-use category	Land-use area, in thousand ha	Profits, in $ million	GHG emissions, in kt. CO_2-e emissions
		2012 Baseline	
Dairy	2,098	2,676	14,819
Sheep & beef	8,591	2,807	24,977
Deer	214	125	778
Other pasture	228	27	783
Arable	341	563	341
Forestry	2,047	1,183	–28,785
Fruits	38	278	10
Pipfruit	16	101	1
Vegetables	37	442	14
Viticulture	42	666	3
Native	9,138	n.a.	n.a.
Other	4,188	n.a.	n.a.
		2030 Reference case	
Dairy	2,299	2,940	16,279
Sheep & beef	7,820	2,577	23,072
Deer	214	125	778
Other pasture	228	27	783
Arable	341	563	341
Forestry	2,598	1,505	–29,617
Fruits	38	278	10
Pipfruit	16	101	1
Vegetables	37	442	14
Viticulture	42	666	3
Native	9,201	n.a.	n.a.
Other	4,188	n.a.	n.a.
		2050 Reference case	
Dairy	2,299	2,940	16,279
Sheep & beef	7,029	2,313	20,635
Deer	214	125	778
Other pasture	228	27	783
Arable	341	563	341
Forestry	3,320	1,906	–37,638
Fruits	38	278	10
Pipfruit	16	101	1
Vegetables	37	442	14
Viticulture	42	666	3
Native	8,868	n.a.	n.a.
Other	4,188	n.a.	n.a.

n.a. means the information is not available; negative values in forestry GHG emissions represents C sequestration.

2.1.2 GHG scenarios

The NZFARM analysis compares the uptake of different mitigation options in response to four GHG price scenarios (Table 2) and compares this to the 2030 and 2050 reference cases. The results of the ESSAM modelling analysis, however, are shown only for 2050. These periods were selected based on the New Zealand Government's aim to reduce GHG emission levels in the future (i.e. the 2030 and 2050 GHG targets). The same GHG price scenarios are considered for Analysis I and Analysis II.

The input data for the 2030 and 2050 periods differ based on the area of different land uses, GHG prices, and payments for C sequestration from forestry. Other information, such as profit, commodity, and environmental indices and per hectare production, remain constant over time. In the future, commodity prices will also change. However, we do not know how these prices will change in response to higher GHG prices or other drivers, and so for this analysis we have assumed commodity prices are unchanged over time in the NZFARM modelling. While this is highly unlikely, keeping the prices constant does enable the analysis to highlight how mitigation option uptake will change as GHG prices change.

We simulate a 2012 baseline, 2030 and 2050 reference cases, and then the GHG price scenarios for 2030 and 2050, as follows.

- Baseline and reference cases: the baseline land use is 2012, and the 2030 and 2050 reference case land uses that were generated are outlined in Dorner et al. (2018). The C sequestration reward, also from Dorner et al. (2018), was \$26.26 and \$37.35 tCO_2^{-1} in 2030 and 2050, respectively. We assume no GHG pricing of biological emissions in the baseline and reference cases. In Dorner et al. (2018) the simulated land uses for the reference cases are a result of the commodity price inputs and the ETS payment for C sequestration in forestry as they affect the dynamic Land Use Change module in the Land Use in Rural New Zealand (LURNZ) model.
- GHG price scenarios: we assume a GHG price was imposed on farmers for their biological GHG emissions from land use for the time periods 2030 and 2050. The GHG prices in 2030 and 2050 are based on the following 2012 GHG prices: GHG1 = \$15/tCO_2-e, GHG2 = \$25/tCO_2-e, GHG3 = \$50/tCO_2-e and GHG4 = \$100/tCO_2-e. These prices are adjusted for each time period based on the interest rate (see Dorner et al. 2018). In all GHG price scenarios, the price for C sequestration payments is the same. As C sequestration from forestry is already rewarded under the ETS, these payments were used to derive land-use areas for the 2030 and 2050 reference cases (see Dorner et al. 2018). Therefore, the C sequestration payment and the GHG prices differ. This allows us to specifically capture the impacts of different GHG prices.

Table 2. Description of GHG prices

Year	C sequestration reward \$/tCO_2-e	GHG price scenarios			
		GHG1 \$/tCO_2-e	GHG2 \$/tCO_2-e	GHG3 \$/tCO_2-e	GHG4 \$/tCO_2-e
2012	\$5.00	\$15.00	\$25.00	\$50.00	\$100.00
2030	\$26.26	\$20.25	\$33.75	\$67.5	\$135.00
2050	\$37.35	\$28.73	\$47.88	\$95.77	\$191.54

In NZFARM we simulate the impact of these GHG prices on agricultural production and profitability for the periods 2030 and 2050. Within ESSAM we look at scenarios GHG1 and GHG4 only for 2050. In ESSAM we cannot run a reference case scenario and then introduce a GHG price together with the associated mitigation options, because the results would be confounded by the (possibly large) effects of a GHG price on the rest of the economy (Stroombergen 2015). Even if there is no price on biological GHG emissions, the sector will be affected by what happens in the rest of the economy. Hence, in ESSAM, for the GHG1 scenario we first run a reference case that has an emissions price of $28.73 on GHG emissions except agricultural methane and nitrous oxide. A second run then places a price on agricultural methane and nitrous oxide emissions, with the assumed GHG1 reductions in emissions being exogenously imposed using the NZFARM results on GHG emissions. The same procedure is used for the GHG4 scenario. The same set of assumptions and baseline and reference information are considered in both Analysis I and Analysis II.

2.2 Assumptions and caveats

Table 3 outlines the main assumptions of our analysis, which focuses on reducing GHG emissions and does not account for any responses to other national or regional policies, such as the NPSFM. In the baseline and reference cases we do not include any uptake of GHG mitigation options so that this analysis can estimate the extent of adoption of each mitigation option in response to different GHG price scenarios.

NZFARM – land-use change

To isolate and better understand the adoption of different mitigation options and the effectiveness of these mitigation options at reducing GHG emissions under different GHG prices, this analysis focuses only on mitigation option uptake and not land-use change (e.g. from dairy to horticulture). The caveat is that there is a mitigation option that includes the partial conversion of dairy or sheep & beef land use to forestry. This option accounts for the conversion of some land on farms being taken out of livestock production.

NZFARM – mitigation options

Seven mitigation options for the dairy sector and three mitigation options for the sheep & beef sector are considered (see section 2.3). These mitigation options were discussed and agreed by BERG as the probable options for farmers to adopt when facing the pricing of biological GHG emissions. Technological breakthroughs (e.g. vaccines) are not considered, because these technologies are not yet available and the efficacy and effect on production systems is not known. We do acknowledge, though, that these types of breakthrough technologies will probably reduce the impact of any future climate policy. Productivity improvements are only considered in Analysis II as a mitigation option.

There are also no C payments associated with the additional land that moves into forestry in the dairy and sheep & beef sectors. This is because it was not possible to determine the amount of C sequestered in this mitigation option from the data provided by DairyNZ, Beef + Lamb New Zealand, and Reisinger et al. (2017).

GHG prices and carbon payments

We assume C sequestration payments and GHG prices will increase over time based on the interest rate. We used the same approach as in Dorner et al. (2018). The price for C sequestration for forestry starts at \$5/tCO_2-e in 2012 and increases annually by the real interest rate (see sections 2.1.1 and 2.2). Four GHG price scenarios are analysed, and the GHG prices in 2030 and 2050 are based on 2012 GHG prices. GHG prices in 2012 are:

- GHG1 = \$15/tCO_2-e
- GHG2 = \$25/tCO_2-e
- GHG3 = \$50/tCO_2-e
- GHG4 = \$100/tCO_2-e

These prices are adjusted for each time period in 2030 and 2050 based on the interest rate. To analyse the effects of GHG prices on the dairy and sheep & beef sectors, we assume that C sequestration payments are the same for each scenario while the GHG price differs between scenarios.

ESSAM

In ESSAM we do not run a reference case and then introduce a GHG price together with the associated mitigation options. This is because the results would be confounded by the (very large) effects of a GHG price on the rest of the economy. Even without a GHG price on biological GHG emissions, the agricultural sector will be affected by the response of other sectors of the economy.

The methane and nitrous oxide emissions in ESSAM are treated as process emissions, but the latter are also linked to fertiliser use – about 5% for dairy, and sheep & beef. Thus, there could be a small effect (in either direction) on GHG emissions on top of the exogenous mitigation policies. The results in ESSAM are reported at the national level, and there is no spatial disaggregation (e.g. by regions) of GHG price effects.

The same set of assumptions and baseline and reference information are considered in both Analysis I and Analysis II.

Table 3. Main assumptions of the modelling for analyses I and II

Parameter	Description of the assumption
Baseline year	2012
Timeframe of analysis (i.e. reference cases)	2030 and 2050
Land uses	In NZFARM: dairy, sheep & beef, deer, other pasture, arable, forestry, fruits, pipfruit, vegetables, viticulture, native, and other In ESSAM: dairy, sheep & beef, horticulture, other farming, and forestry
Land-use change	No explicit land-use change, except planting forestry as a mitigation option.
Land uses that consider mitigation options	Dairy farms and sheep & beef farms can adopt different mitigation options
Interest rate	Real interest rate is the nominal 90-day bank bill rate minus the CPI projections, which is constant after 2021. The nominal interest rate is the 90-day bank bill rate.[5]
GHG prices	The GHG prices in each scenario are based on initial prices of $15, $25, $50 and $100 per tCO_2-e in 2012. These prices are then projected for 2030 and 2050 based on the interest rate.
Payments for C sequestration in forestry	The initial price for forestry C sequestration was $5/$tCO_2$-e in 2012. This value is projected for 2030 and 2050 based on the interest rate.
Dairy area	An increase from 2,098,000 ha in 2012 to 2,299,000 ha in 2030 and 2050 (i.e. an increase of about 10% from 2012 values) in dairy area was projected until 2025, based on Dorner et al. (2018).
Sheep & beef area	A reduction from 8,591,000 ha in 2012 to 7,820,000 ha in 2030 and further to 7,029,000 ha in 2050 (i.e. a decrease of 9% in 2030 and 18% in 2050 from 2012 values) in sheep & beef area over time was projected, based on Dorner et al. (2018).
National Policy Statement for Freshwater Management	The analysis does not account for any changes in the adoption of different management practices by farmers to meet any requirements resulting from the implementation of the National Policy Statement for Freshwater Management.

2.3 Mitigation options

2.3.1 Dairy farm mitigation options

We considered seven mitigation options for the dairy sector for the NZFARM modelling. These mitigation options, along with their effectiveness, were provided by DairyNZ. These options are currently available. Table 4 and Appendix 3 describe each mitigation option. The impact on profitability and GHG emissions of these mitigation options on a per hectare basis are outlined in Tables 33 and 34 in Appendix 4.

[5] The 90-day bank bill rate is projected from 2017 to 2021 using the Treasury 2017 rate. The 2021 interest rate is constant for the time period. Real interest rates are the nominal 90-day bank bill rate minus CPI projections, also constant after 2021. This gives a real interest rate of 1.8% from 2021 onwards.

Table 4. Description of mitigation options considered for dairy farms

Mitigation option	Description	Mitigation intensities/subtypes			
		a	b	c	d
(1) Output approach reducing GHG emissions	Farm-specific, cost-effective farm system changes targeting nitrogen (N) fertiliser, supplementary feed, stocking rate and irrigation efficiency (Canterbury only) to reduce GHG emissions	5% decrease in GHG emissions	10% decrease in GHG emissions	15% decrease in GHG emissions	20% decrease in GHG emissions
(2) Reduction in fertiliser use	N fertiliser reductions, then reduce stocking rate to match feed supply and demand	25% decrease in N fertiliser	50% decrease in N fertiliser	75% decrease in N fertiliser	100%decrease in N fertiliser
(3) Change in supplement feed	High protein imported supplement reductions, then either replaced with a low protein alternative or reduce stocking rate to match feed supply and demand	Reduce high protein feed by 50% and replace with low protein feed	Remove all high protein feed and replace with low protein feed	Reduce high protein feed by 50% and reduce stocking rate	Reduce all high protein feed and reduce stocking rate
(4) Reduction in cow numbers and same milk production per cow	Stocking rate (SR) reductions, then reduce feed and N fertiliser inputs to match feed supply and demand. Milk production per cow remains constant but total farm milk production reduces	5% decrease in SR	10% decrease in SR	15% decrease in SR	20% decrease in SR
(5) Once-a-day milking	Introduce once-a-day milking	Half season	Entire season		
(6) Planting forestry	Plant forestry on effective milking platform, then reduce cow numbers to maintain the same SR on effective milking area with other inputs reduced	5% of farm in forestry	10% of farm in forestry	15% of farm in forestry	20% of farm in forestry
(7) Reduce cow numbers and increase milk production per cow	SR reductions and increase in milk production per cow. Profits per hectare almost do not change from reducing SR when compared to the no mitigation practice	5% decrease in SR	10% decrease in SR	15% decrease in SR	20% decrease in SR

As can be seen from Tables 33 and 34 in Appendix 4, on average for a per hectare basis, the dairy mitigation option with the greatest reduction in GHG emissions is the reduction in cow numbers while maintaining milk production per cow. The costliest mitigation option for the dairy sector is planting forestry. In addition, the planting forestry mitigation option is only a partial planting on the dairy and sheep & beef sectors. Therefore, for this mitigation option we use net GHG emissions, which is the difference between GHG emissions from farming and C sequestered by forestry. There are also no C payments associated with the additional land that moves into forestry in the dairy sector. This is because it was not possible to determine the amount of C sequestered in this mitigation option from the data provided by DairyNZ.

Once-a-day milking has the lowest reduction in GHG emissions but the smallest impact on profitability. Reducing cow numbers while increasing milk production per cow has similar per hectare profits to the no mitigation option but reduces GHG emissions. It should be noted that these are average effects, as there are differences across dairy systems and regions in profitability and GHG emissions. For more information on the description of mitigation options, see the documentation on mitigation options provided by the DairyNZ Economic Group (2017, 2018).

We conducted two analyses that involved different sets of mitigation options for the dairy sector:

- Analysis I, which included mitigation options 1–6 for the dairy sector (see Table 5)
- Analysis II, which included mitigation options 1–7 for the dairy sector (see Table 5); this analysis included an additional mitigation option that involves reducing dairy cow numbers while increasing milk production per cow (i.e. increased dairy sector productivity).

These analyses reflect a realistic set of mitigation options (Analysis I) available to the dairy sector and a more optimistic set of mitigation options where productivity improvements are available and would be widespread across the dairy sector (Analysis II). Based on discussions with BERG members, we assume that all dairy mitigation options can be adopted and there is no constraint on adoption area.

We did not include the following mitigation options in our analysis:

- dairy stand-off pads, because they have minor effects on reducing GHG emissions and may even increase GHG emissions (Reisinger et al. 2017)
- the nitrification inhibitor DCD, because it is not available after the discovery of residues in dairy produtcs, and it had high costs and only minor GHG emission reductions (Reisinger & Clark 2016); note that Reisinger et al. (2017) stated that urease inhibitors have limited GHG reduction potential
- manure management, selective breeding, and vaccines.

Table 5. Dairy mitigation options considered for Analysis I and for Analysis II

Mitigation option	List of mitigation options considered in different analysis, Yes/No	
	Analysis I	Analysis II
(1) Output approach reducing GHG emissions	Yes	Yes
(2) Reduction in fertiliser use	Yes	Yes
(3) Change in supplement feed	Yes	Yes
(4) Reduction in cow numbers and same milk production per cow	Yes	Yes
(5) Once-a-day milking	Yes	Yes
(6) Planting forestry	Yes	Yes
(7) Reduction in cow numbers and increase in milk production per cow	No	Yes

2.3.2 Sheep & beef farm mitigation options

The mitigation options and their effectiveness for the sheep & beef sector are based on the options contained in Reisinger et al. 2017. Of the six mitigation options listed in this report, we include three mitigation options for this analysis (Table 6). Based on Reisinger et al. 2017, we included intensities/subtypes of mitigation options only for forestry.

Table 6. Description of mitigation options considered for the sheep & beef sector

Mitigation option	Description
Reduction in stocking rate and maintain production	Stocking rates reduced, while sheep & beef production remains the same per animal
Removal of breeding cows	Replace breeding cows with surplus dairy animals
Planting forestry	• Planting forestry on 10%, 20% and 30% of pasture • Planting forestry on 10% of pasture and total production is reduced • Planting forestry on marginal lands and maintain production

Based on the industry recommendations, we consider reducing stocking rate and maintaining productivity and do not consider reducing stocking rate with increased productivity. With the replacement of breeding cows, most of this change has already occurred on land suitable for having surplus dairy animals. Industry recommendations, however, suggest there is still some scope for a further reduction of breeding stock, but it is small, perhaps 5% of the land area (Paul McCauley, pers. comm., June 2018). Therefore we cap the adoption of this mitigation option at 5% of the suitable sheep & beef land area.

The adoption of other mitigation options for the sheep & beef sector presented in Table 6 is not constrained. The challenges with managing the disease *Mycoplasma bovis* may also restrict the movement of cattle in New Zealand, at least in the short term. In both analyses, we consider the same set of mitigation options for the sheep & beef sector.

The other mitigation options in Reisinger et al. 2017 not included in the modelling were altering the sheep to cattle ratio, removing N fertiliser usage, and increasing male /

decreasing female cattle. Reisinger et al. (2017) found that these mitigation options had negligible effects on GHG emissions.

The impact on per hectare profitability and GHG emissions for sheep & beef mitigation options is outlined in Table 35 in Appendix 4. This table shows that replacing breeding cows with surplus dairy animals can substantially increase profits but only slightly reduces GHG emissions. Planting forestry reduces profits (except on some marginal land) but gives the largest reduction in GHG emissions for the sheep & beef sector.

2.4 Data sources

The data used in this analysis are based on the year 2012. We use a detailed land-use map of New Zealand to derive the initial (baseline) enterprise areas across regions and farm systems data from DairyNZ, Beef + Lamb New Zealand, and other secondary data sources to parameterise the farm systems for NZFARM. The 2012 baseline land-use area was derived from Agribase and the NZ Land Cover Database. The land-use areas for the 2030 and 2050 reference cases were generated using the LURNZ model, and they are described in Dorner et al. (2018).

Information on profit, milk solid production, stocking rate, and environmental outputs from 27 dairy farms that include five dairy systems was obtained from DairyNZ. DairyNZ used FARMAX[6] and OVERSEER[7] to derive the impacts on profits and GHG emission levels[8] from the different dairy systems with a range of mitigation/management options (DairyNZ Economic Group 2017, 2018). Information on the dairy mitigation options provided by DairyNZ is outlined in Tables 33 and 34 in Appendix 4. These tables show the variability in GHG emissions and profits on a per hectare basis across the different dairy systems and regions. For more information on the dairy mitigation options, see also DairyNZ Economic Group 2017, 2018.

Data on profit, stocking rate (sheep, beef cattle, deer and goats) and production (wool, lamb, beef, and venison) from different sheep & beef systems were obtained from the sheep & beef farm survey of Beef + Lamb New Zealand. Based on these surveys, we considered six systems/types for the sheep & beef sector (see Appendix 3), and the information on these mitigation options is outlined in Table 35 in Appendix 4.

To estimate the GHG emissions for all land uses, except dairy, we relied on the tier two methodology of the New Zealand GHG inventory (MfE 2017). For calculating GHG emissions from the sheep & beef sector, we considered the stocking rate and fertiliser application levels. We also obtained information from Horticulture New Zealand on profit, crop yields, GHG emissions, fertiliser application levels, and area distribution for pipfruit, vegetables, viticulture, and other fruits. Profit and GHG emissions for arable crops were obtained from Daigneault et al. (2017).

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[6] http://www.farmax.co.nz/

[7] https://www.overseer.org.nz/

[8] In this analysis we only considered biological emissions from farming. Therefore, any embodied GHG emissions related to farming were removed.

3 Qualitative assessment of mitigation options uptake

A qualitative assessment of mitigation options was undertaken to ascertain which mitigation options were more likely to be implemented by dairy and sheep & beef farmers. This assessment was based on discussions with DairyNZ and Beef + Lamb New Zealand sector groups. During this assessment, we endeavoured to identify the order in which different mitigation options are likely to be taken up by farmers, constraints on their uptake, and why different practices might or might not be adopted. The barriers assessment is based on selected relevant literature and surveys, and consultation with BERG members and other New Zealand industry experts.

3.1 Barriers to the uptake of mitigation options

To get an indication of some general indicative barriers to the uptake of mitigation options, we reviewed studies that assessed the uptake of climate change mitigation options (Brown 2015; Motu 2017; Wreford et al. 2017). Overall, it was noted that the relative importance of barriers to the uptake of a mitigation option varied depending on circumstances, including socio-economic characteristics, farming systems, biophysical conditions, existing infrastructure, regulations, and institutions. This was confirmed by BERG members and sector experts (from DairyNZ and Beef + Lamb New Zealand).

The general categories for adoption barriers were outlined by Motu (2017), who identified seven broad categories of barriers to the adoption of no-cost mitigation options for agricultural emissions in New Zealand (Table 7).

Table 7. Categories of barriers to the uptake of no-cost options for mitigation of agricultural emissions

Barrier	Description	Mapping to Wreford et al. 2017 barriers
Efficiency or cost	Efficiency refers to situations in which the simple financial profitability test fails to measure correctly the true economic impact on the farmer, so the option appears to be no/ low cost, but is costly to the farmer when properly analysed	Effect on profitability and performance, cost of adoption, hidden and transaction costs
Information	Situations in which no- or low-cost options are not utilised because of imperfect availability of information.	Adequate knowledge and awareness
Market structure/institutional	Situations where market or institutional failures inhibit adoption.	Access to capital, infrastructure and complementary inputs, land tenure
Externalities	A source of barriers if a portion of the financial costs or benefits of an option are borne by a party other than the one that decides whether or not to adopt the option. Such separation of impacts from decision-making can potentially arise because of land-holding or contractual relationships, or because of impacts that spread through a supply chain.	Perception of leakage
Regulatory or policy barriers	Due to existing or potential constraints from public policy or the law.	Environmental and climate knowledge, misaligned policy
Risk and uncertainty	Can inhibit the adoption of new technologies or practices. This can operate both through rational calculation of the financial consequences of risk and through cognitive inabilities to process uncertainty.	Risk management
Behavioural barriers	When cognitive biases tend to push economic agents away from rational profit maximisation in a predictable or systematic way.	Social and cultural barriers, behaviour and cognitive factors

Source: Motu 2017

Wreford et al. (2017) also evaluated and prioritised barriers to the adoption of climate-friendly practices in agriculture based on their reported strength and the degree of agreement in the literature. These barriers were mapped to the Motu 2017 barriers given in Table 7.

Barriers relating to the actual or perceived effects of GHG mitigation actions on farm performance and profitability appear as the top-ranking barrier internationally (Wreford et al. 2017). This is reflected in the feedback from sector experts. Adequate knowledge and awareness of climate change impacts and how they might influence on-farm decision-making and risk management were also highlighted as high-ranking barriers to mitigation action. Both barriers were also identified by sector experts as high-ranking barriers to pursuing no-cost or low-cost mitigation options. Environmental and climate policies were also identified as high priority barriers to or enablers of mitigation action. These findings from the international literature were also reflected in the domestic literature and expert opinions.

The cost of adoption, hidden and transaction costs, social and cultural factors, the perception of carbon leakage, access to credit, and misaligned policies were identified as barriers that play a less important role in influencing no-cost or low-mitigation actions by farmers (Wreford et al. 2017). An additional consideration is land tenure and the availability and access to infrastructure and complementary inputs (such as water irrigation systems). Other barriers, such as those associated with behavioural and cognitive factors, were found to be relatively less important overall (Wreford et al. 2017). These are relatively high-level barriers.

To ascertain more nuanced reasons why mitigation options may not be adopted, we used the Survey of Rural Decision Makers (SRDM; Brown 2015). The SRDM covers all farming sectors in New Zealand, and the respondents are land managers/owners of rural properties. These survey results are based on general farm management practices and practices targeted at improving water quality. However, it is likely that these reasons would also hold for mitigation options aimed at reducing GHG emissions.

The management practices/technologies surveyed within SRDM were nutrient management plans, fencing large streams, plans to manage soil, plans to reduce pugging, constructing pads/barns, and effluent management systems. The most common reasons for farmers not adopting these management practices/technologies were lack of finances, costs outweighed benefits, no perceived environmental benefit, had not seen the practice/technology demonstrated, and trialling the practice/technology was not simple. These reasons were noted by some portion of the farming community for all these practices/technologies. For the practices that involved plans, a lack of skills and good advice were noted as reasons for not adopting. No regulatory pressure was the other reason noted for many practices/technologies.

Conversely, the SRDM also provides insights into the reasons why practices/technologies were adopted. Stewardship and having the skills and benefits outweigh the costs were the most common reasons noted by survey respondents. Having the finances, being given good advice, ease of trialling, and have seen the practice/technology demonstrated were also noted, but were less common reasons. For some practices/technologies, regulatory pressure was the reason for adoption by some farmers. Interestingly, social pressure and banking/industry pressure were rarely listed as reasons why a practice/technology was adopted.

The SRDM provides overarching insights into the reasons why farmers adopt or don’t adopt different practices/technologies. In the sections below we provide additional information from DairyNZ and Beef + Lamb New Zealand on the uptake of specific mitigation options considered in this analysis.

3.2 Uptake of mitigation options

Reflecting the literature, the sector groups noted that the reason why mitigation options may or may not be taken up is dependent on the circumstances of individual farmers. This was particularly so for sheep & beef farmers, where there is a large heterogeneity in land characteristics and farmer behaviour.

3.2.1 Dairy

Of the dairy mitigation options being considered, DairyNZ indicated that reducing fertiliser use, changing input feeds, and reducing cow numbers (options 2, 3, 4, and 7 in section 2.3) were the most likely options to be adopted based on farm preference, potential to reduce GHG emissions, and cost of such mitigations. Once-a-day milking for half or an entire season (option 5) was thought to be less likely, and if it was taken up it was more likely in Northland, Taranaki, and perhaps the West Coast. Planting forestry (option 6) was thought to be the least likely to be taken up, and would be restricted to land that was land-use class 4 and above.

In terms of potential timing of adoption, all the options are currently able to be implemented. DairyNZ indicated there were no significant technological barriers to these options, and the most important factor in determining the likelihood of any of these mitigation options being adopted and the rate of adoption would be the influence of environmental or climate policy. For example, if farmers have a policy-determined nitrogen leaching amount for which they are aiming, then this will directly influence their mitigation behaviours. DairyNZ noted that the extent and degree to which any of the options are adopted also depends on the policy/option under which each farm is currently operating (e.g. would a farm be starting from high or low levels of supplementary feed or nitrogen fertiliser use).

3.2.2 Sheep & beef

For the sheep & beef sector, Beef + Lamb New Zealand indicated that reductions in stocking rate and planting of trees (options 1 and 3 in section 2.3) were the most likely and potentially most effective options. As with dairy, the form and level of ambition of environmental or climate policies were identified as important factors in determining the likelihood of uptake and the rate of uptake of mitigation options, as is the current farm operation (e.g. nitrogen fertiliser usage or stocking rate). For instance, policy incentives are likely to be a driving force behind any tree planting on sheep & beef land area, and most forest planting would be on marginal land. As noted earlier, there is less opportunity for replacing cows with surplus dairy stock, as this has largely already happened where the land is suitable.

4 Analysis I

In Analysis I we consider the dairy mitigation options 1−6 and all the mitigation options available for sheep & beef (see section 2.3).

4.1 Analysis I: Agricultural sector impacts based on NZFARM modelling

In this section we present the estimated responses to different GHG prices for 2030 and 2050 using the NZFARM model for Analysis I. Because NZFARM is not a dynamic model, reduction in the GHG emissions in 2050 is independent of the cost of reducing the GHG emissions in 2030. This means that the scenario results should be compared against the reference case for the relevant year (2030 or 2050) and not between 2030 and 2050.

4.1.1 Summary of results

The results show that imposing higher GHG prices incentivises dairy farmers to adopt a range of mitigation options that reduce GHG emissions between 1% and 9% in 2030 and between 2% and 15% in 2050 (Table 8). In particular, the dairy sectors in Canterbury, Southland, Taranaki, and Waikato have the largest absolute reductions in GHG emissions (see Tables A9 and A12 in Supplementary Material I). Concurrently, profits decrease between 9% and 70% in 2030 and between 14% and 98% in 2050. Such large decreases in profits, even under low GHG prices (i.e. GHG1), result from some dairy systems having high GHG emissions and low profitability, which means GHG prices increase the costs for dairy and reduce their profits. The regional effects on profits show that the profits in Canterbury reduce by almost 140%, especially for dairy systems 3 and 5, which become highly unprofitable in this region (see Supplementary Material I).

In 2030 the uptake of mitigation options by the dairy sector is similar for the GHG1 and GHG2 price scenarios (Table 11). Under such GHG price levels, the regions that allocate most of their area to mitigations are Marlborough, Nelson, Tasman, and the West Coast, which adopt the output approach and planting forestry mitigation options with dairy systems 2 and 3, respectively (see Tables A1 and A2 in Supplementary Material I). These lower GHG prices provide little incentive for dairy farmers to switch to mitigation options that achieve greater reductions in GHG emissions. Profitability is lower at GHG2 than at GHG1 as dairy farmers are paying a higher GHG price for their emissions. As expected, higher GHG prices do result in dairy farmers adopting higher-cost mitigation options that achieve greater GHG emission reductions (Table 15). It is not until GHG4 in 2030 that the mitigation options that reduce fertiliser use and cow numbers are adopted. In 2050, under the highest GHG price, the dairy sector does not use the no mitigation practice.

For the sheep & beef sector, GHG emissions reduce between 21% and 29% in 2030 and between 20% and 34% in 2050. Canterbury, Hawke's Bay, Otago, and Waikato have the largest absolute reductions in GHG emissions (see Tables A21 and A24 in Supplementary Material I). Profits in 2030 decrease between 9% and 89%, and profits in 2050 decrease between 15% and 123% (Table 9). The large reductions in sheep & beef sector profits at low GHG prices are due to the high GHG emissions and low profits in this sector. At higher GHG prices, greater areas are planted in forestry to reduce GHG emissions and the negative impact on profitability from GHG prices on emissions (Table 12). Profitability, however, declines and the sheep & beef sector even incurs losses, because they are paying very high prices for their GHG emissions. In such cases, farmers might shift to another land use or even abandon farming, but this was not considered in the analysis.

In aggregate, considering all land uses, GHG emissions reduce between 12% and 20% in 2030 and between 12% and 25% in 2050 as the dairy and sheep & beef sectors respond to the pricing of GHG emissions and adopt different mitigation practices to reduce GHG emissions (Table 10). The corresponding impact on profits from these sectors results in reduced profits of between 6% and 47% in 2030 and between 8% and 61% in 2050 as GHG prices increase. The effects on agricultural and forestry land uses of GHG prices need to be treated with caution, as we do not consider the land-use change that might occur when farmers start to experience larger profit reductions from GHG prices.

Table 8. Summary results for dairy changes under different GHG prices with respect to the reference case for Analysis I

Scenario	Profit, in $ million	GHG emissions, in 1,000 tCO_2-e
Simulation results for 2030		
Reference case	2,940	16,279
GHG1 ($20.25/$tCO_2$-e)	–9%	–1%
GHG2 ($33.75/$tCO_2$-e)	–17%	–2%
GHG3 ($67.5/$tCO_2$-e)	–35%	–3%
GHG4 ($135/$tCO_2$-e)	–70%	–9%
Simulation results for 2050		
Reference case	2,940	16,279
GHG1 ($28.73/$tCO_2$-e)	–14%	–2%
GHG2 ($47.88/$tCO_2$-e)	–24%	–2%
GHG3 ($95.77/$tCO_2$-e)	–50%	–5%
GHG4 ($191.54/$tCO_2$-e)	–98%	–15%

Table 9. Summary results for sheep & beef changes under different GHG prices with respect to the reference case for Analysis I

Scenario	Profit, in $ million	GHG emissions, 1,000 tCO_2-e
Simulation results for 2030		
Reference case	2,577	23,072
GHG1 ($20.25/$tCO_2$-e)	–9%	–21%
GHG2 ($33.75/$tCO_2$-e)	–19%	–21%
GHG3 ($67.5/$tCO_2$-e)	–43%	–21%
GHG4 ($135/$tCO_2$-e)	–89%	–29%
Simulation results for 2050		
Reference case	2,313	20,635
GHG1 ($28.73/$tCO_2$-e)	–15%	–20%
GHG2 ($47.88/$tCO_2$-e)	–29%	–20%
GHG3 ($95.77/$tCO_2$-e)	–63%	–22%
GHG4 ($191.54/$tCO_2$-e)	–123%	–34%

Table 10. Summary results considering all agricultural and forestry land uses under different GHG prices with respect to the reference case for Analysis I

Scenario	Profits, in $ million	GHG emissions, 1,000 tCO_2-e
	Simulation results for 2030	
Reference case	9,224	41,281
GHG1 ($20.25/tCO2-e)	–6%	–12%
GHG2 ($33.75/tCO2-e)	–11%	–12%
GHG3 ($67.5/tCO2-e)	–23%	–13%
GHG4 ($135/tCO2-e)	–47%	–20%
	Simulation results for 2050	
Reference case	9,362	38,844
GHG1 ($28.73/tCO2-e)	–8%	–12%
GHG2 ($47.88/tCO2-e)	–15%	–12%
GHG3 ($95.77/tCO2-e)	–31%	–13%
GHG4 ($191.54/tCO2-e)	–61%	–25%

4.1.2 Land-use and mitigation options

Imposing GHG prices results in the adoption of several mitigation options.[9] For most mitigation options, the rate of adoption increases with higher GHG prices. In addition, the rate of uptake varies between different mitigation options depending on their cost-effectiveness. See Tables 11 and 12 for the area of each mitigation option at different GHG prices for the dairy and sheep & beef sectors. The distribution of mitigation option adoption depends on profitability and GHG emissions (which, with GHG prices, is a cost for farmers) of the different dairy systems in each region with these mitigation options. Tables 33–35 in Appendix 4 show the data on GHG emissions and profits on a per hectare level for each mitigation option in the dairy and sheep & beef sectors.

In 2030 the results for the dairy sector show that for GHG1, GHG2, and GHG3 changing feed inputs, using an output approach, once-a-day milking, and planting forestry are the mitigation options adopted. With low GHG prices only dairy farmers in Marlborough, Nelson, Tasman, and the West Coast use mitigation options on all their area, because of higher profitability with mitigation options than profitability with no mitigation for the dairy sector in these regions (see Table A1 in Supplementary Material I). The mitigation options adopted in these regions are the output approach (on 40% of a region's area) and planting forestry (on 60% of a region's area). Only these four regions adopted the forestry planting option due to its higher profitability and GHG emission reduction potential for dairy system 2 in comparison to other regions and dairy systems. Other regions adopted the output approach, change in supplementary feed, once-a-day milking, and no

[9] In the reference cases we assume no farms have taken up mitigation options. This allows us to assess the adoption rate of various mitigation options.

mitigation practices. Also, with the exception of Canterbury, dairy farmers adopted different mitigation practices on most of their land, even under the low GHG price (i.e. GHG1).

All mitigation options are adopted in GHG4. In GHG4, planting forestry mitigation is still only adopted in Marlborough, Nelson, Tasman, and the West Coast (see Table A2 in Supplementary Material I). In these regions, establishing forestry on a dairy platform has a higher potential to reduce GHG emissions and a lower profit decrease than other mitigation options with GHG prices. Once-a-day milking was noted by sector experts as a mitigation option that is less likely to be adopted. However, in our analysis the relative profitability of this mitigation option compared to other options is higher. There are two implications of this. First, if farmers are faced with GHG prices, it may incentivise the uptake of more and different types of mitigation options than in the past, including once-a-day milking. Second, if once-a-day milking is going to be beneficial to the sector in terms of reducing its GHG emissions and maintaining profitability, then the barriers to its adoption need to be identified and addressed.

In 2050 there is a similar story for GHG1 and GHG2 as in 2030, but in GHG3 all mitigation options have been taken up by different farmers (Table 11). This is because emissions prices are increasing over time and become costly, which incentivises farmers to adopt more options. Interestingly, for GHG4 in 2050 it is no longer profitable to implement once-a-day milking, and instead more farmers reduce cow numbers to reduce the negative impacts on profits from the higher GHG prices. While reducing cow numbers still reduces profitability (Table 13), the negative impact on profitability is less than taking up more of the other mitigation options due to high GHG prices.

Also, with higher GHG prices dairy farmers adopt different mitigation options. The reason for this is the heterogeneity in farm profits with different mitigation options and GHG emissions across dairy systems and regions. Hence, some systems might be preferable in some regions than in others (see Tables A1–A4 in Supplementary Material I). For example, with the GHG4 price, the dairy sector in Canterbury and Otago mainly adopts the reduction in cow numbers and allocates some area to the output approach, whereas the dairy sector in Marlborough, Nelson, Tasman, and the West Coast adopts planting forestry and reduction in cow numbers.

Across all prices, planting forestry has a lower uptake compared to most other mitigation options for most GHG prices. This is because the gross value of dairy is higher than for forestry. The forestry mitigation option is costly, but is still the preferred option on about 5% of the milking platform in regions such as Marlborough, Nelson, Tasman, and the West Coast (see Tables A1−A4 in Supplementary Material I). Farmers in these regions adopt this mitigation option at low GHG prices (i.e. GHG1). Further increasing the forestry area in the dairy sector (i.e. planting forestry on 10%, 15%, and 20% of the milking platform), even at higher GHG prices, can be a less cost-effective option for farmers to reduce GHG emissions in comparison to other mitigation options (see Tables 33 and 34 in Appendix 4 for the data on GHG emissions and profits for the dairy mitigation options). The dairy sector in the Bay of Plenty and Waikato adopts the output approach, change in supplementary feed, and reduction of cow numbers, whereas in Auckland, Gisborne, Hawke's Bay, Manawatu–Wanganui, Northland, Taranaki, and Wellington the dairy sector, in addition to these mitigation options, adopts reduction in fertiliser use (see Table A4 in Supplementary Material I).

For the sheep & beef sector, a portion of all mitigation options is adopted at each GHG price in 2030 (Table 12). There is a similar story in 2050, except that reducing stocking rates is not taken up in GHG4. Planting forestry has the highest adoption rate, followed by a reduction in stocking rates for most GHG prices. For GHG4 almost 95% of all sheep & beef area has taken up the forestry mitigation option. Tables A13 and A16 in Supplementary Material I show that forestry is planted on marginal areas on sheep & beef farms under the lowest GHG price (GHG1). The sheep & beef sector in Canterbury, Marlborough, Nelson, Otago, Southland, Tasman, and the West Coast practise 'no mitigation' along with the mitigation options, while other regions allocate their entire land area for mitigation options (Table A13 in Supplementary Material I). In Auckland and Northland, most of the sheep & beef farms allocate their land for planting forestry.

With the highest GHG price in 2050, most of the forestry is planted on 30% of sheep & beef farm area located in the hills (Table A16 in Supplementary Material I). This result shows that with GHG prices, farmers partially change their land use and shift to forestry. The removal of breeding cows is highly profitable (Table 35 in Appendix 4), and the allowable area[10] of this mitigation option is already taken up at the lowest GHG price. However, only sheep & beef farms in Otago and Southland adopt the removal of breeding cows option, as this mitigation can generate the largest profits in these two regions (considering the assumed allowable area of this mitigation for the sheep & beef sector).

[10] In this analysis, the additional area able to remove breeding stock is limited to 5% (see section 2.3).

Table 11. Area of mitigation options adopted by dairy under different GHG price scenarios in 2030 and 2050 for Analysis I, in 1,000 ha [11]

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 ($20.25/t$CO_2$-e)	GHG2 ($33.75/t$CO_2$-e)	GHG3 ($67.5/t$CO_2$-e)	GHG4 ($135/t$CO_2$-e)
No mitigation	1,021	1,021	595	156
Output approach	258	258	607	743
Reduction in fertiliser use	0	0	0	75
Change in supplementary feed	550	550	627	731
Reduction in cow numbers and same milk production per cow	0	0	0	309
Once-a-day milking	390	390	390	205
Planting forestry	79	79	79	79
	Simulation results for 2050			
	GHG1 ($28.73/t$CO_2$-e)	GHG2 ($47.8/t$CO_2$-e)	GHG3 ($95.77/t$CO_2$-e)	GHG4 ($191.54/t$CO_2$-e)
No mitigation	1,021	878	595	0
Output approach	258	258	413	600
Reduction in fertiliser use	0	0	217	160
Change in supplementary feed	550	694	552	765
Reduction in cow numbers and same milk production per cow	0	0	53	695
Once-a-day milking	390	390	390	0
Planting forestry	79	79	79	79

[11] Note that in some instances the results look identical due to rounding of the numbers.

Table 12. Area of mitigation options adopted by sheep & beef under different GHG price scenarios in 2030 and 2050 for Analysis I, in 1,000 ha

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 ($20.25/t$CO_2$-e)	GHG2 ($33.75/t$CO_2$-e)	GHG3 ($67.5/t$CO_2$-e)	GHG4 ($135/t$CO_2$-e)
No mitigation	1,606	1,606	1,398	0
Reduction in stocking rates	2,321	2,321	2,321	1,262
Removal of breeding cows	391	391	391	391
Planting forestry	3,502	3,502	3,709	6,167
	Simulation results for 2050			
	GHG1 ($28.73/t$CO_2$-e)	GHG2 ($47.8/t$CO_2$-e)	GHG3 ($95.77/t$CO_2$-e)	GHG4 ($191.54/t$CO_2$-e)
No mitigation	1,471	1,471	746	0
Reduction in stocking rates	2,030	2,030	2,030	0
Removal of breeding cows	351	351	351	351
Planting forestry	3,177	3,177	3,902	6,678

4.1.3 Profits

Profits decrease with higher GHG prices in the dairy and sheep & beef sectors. In 2030 the results show that profits for dairy decreased by 9%, 17%, 35%, and 70% when imposing GHG1, GHG2, GHG3, and GHG4 prices, respectively (Table 8). In 2050, dairy profit fell by 14%, 24%, 50%, and 98% for GHG1, GHG2, GHG3, and GHG4, respectively.

Undertaking no mitigation provides the largest share of the profits in GHG1, GHG2, and GHG3 in comparison to specific mitigation options (Table 13).[12] Under these GHG prices the 'no mitigation' option occupies the largest area of dairy in comparison to any specific mitigation (Table 11). In particular, dairy in Canterbury mainly generates profits from the 'no mitigation' option (Table A5 in Supplementary Material I). In contrast, dairy in Marlborough, Nelson, Tasman, and the West Coast generates profits from mitigation options such as the output approach (40% of profits) and planting forestry (60% of profits). Other regions adopt both 'no mitigation' and mitigation options.

By GHG4, prices have reached the point where it means that most dairy farms in 2030 and all dairy farms in 2050 will implement some form of GHG mitigation option. At this price there is going to be a substantial reduction in dairy profits, making dairy farming a low-profit or unprofitable activity.[13] In all the regions, some dairy systems will have losses

[12] We assume in the reference case that all land-use areas are allocated for no mitigation option due to insufficient data on the current distribution of mitigation options across regions and farm types. We also do not consider water quality policies such as the NPSFM, which also influence the adoption of mitigation options.

[13] With high GHG prices, to reduce the reduction in profits farmers might increase milk prices.

(Table A8 in Supplementary Material I). For instance, dairy system 2 in Auckland and Northland adopts reduction in fertiliser use and in cow numbers and still has losses with these options. Because of high GHG prices, Canterbury, Marlborough, Nelson, Tasman, and the West Coast regions have losses from dairy activities even if they adopt mitigation options. Among the regions, Canterbury has the largest losses from the highest GHG price (GHG4).

To reduce the substantial negative effects of high GHG prices, there is an increase in the mitigation option that reduces cow numbers while maintaining milk production per cow, which is the most GHG-reducing mitigation option but a highly costly option (see Tables 33 and 34 in Appendix 4). Due to its high costs and GHG prices, the adoption of this mitigation option leads to losses in the dairy sector (costs are higher than profits), yet this option is still less costly than other mitigation options under high GHG prices.

We do not consider land-use change (we only include partial forestry planting at farms) in this analysis, but when farmers face high losses they may change their land use and enterprise structure (e.g. from dairy farming to horticultural farming). Also, high GHG prices might force farmers to quit farming, as farmers might not be able to cover their expenses, even with these mitigation options.

Reducing cow numbers while using the maintaining milk production per cow mitigation option leads to financial losses in 2050, and such losses are highest in Canterbury, followed by Southland and the West Coast (Table A8 in Supplementary Material I). However, these losses are less than if other mitigation options are adopted. The losses come from some dairy systems in some regions being unable to generate sufficient profits to cover the additional costs associated with higher GHG prices.

At low GHG prices, sheep & beef farms generate most of their profits from taking up mitigation options (Table 14). The sheep & beef sector in Canterbury, Marlborough, Nelson, Otago, Southland, Tasman, and the West Coast has the largest share of profits from no mitigation (Table A17 in Supplementary Material I). This shows that not adopting some form of mitigation option is not optimal for most farmers in the sheep & beef sector, even under the low GHG price (i.e. GHG1). (For an indication of mitigation options adopted in various areas, see Table 12).

The largest profits come from reducing the stocking rate (mainly for Gisborne, Hawke's Bay, and Waikato), followed by planting forestry (in Auckland, Canterbury, Northland, and Otago). Sheep & beef farming has lower farm profits at higher GHG prices. At GHG4, planting forestry results in losses, as some sheep & beef farms do not generate enough profit to cover the cost of high GHG prices. In particular, all the sheep & beef systems/types in Canterbury, Marlborough, Nelson, Tasman, and the West Coast incur financial losses when the highest GHG price (GHG4) is implemented in 2050 (Table A20 in Supplementary Material I), whereas the sheep & beef sector in Gisborne, Hawke's Bay, and Southland overall still generates profits.

The sheep & beef sector in the remaining regions overall has losses, but some systems/types have maintained profits. When the high GHG prices are implemented, planting forestry is the least costly option in comparison to adopting other mitigation options in the sheep & beef sector, thus leading to its adoption in most regions (see

Supplementary Material I). These losses could be mitigated if farmers changed land use, there were technological innovations, or farmers could exit the agricultural sector. However, these options are not considered in this analysis.

Table 13. Dairy profits under different GHG price scenarios in 2030 and 2050 for Analysis I, in $ million

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 ($20.25/t$CO_2$-e)	GHG2 ($33.75/t$CO_2$-e)	GHG3 ($67.5/t$CO_2$-e)	GHG4 ($135/t$CO_2$-e)
No mitigation	1,316	1,212	569	103
Output approach	138	117	474	348
Reduction in fertiliser use	0	0	0	47
Change in supplementary feed	690	640	496	273
Reduction in cow numbers and same milk production per cow	0	0	0	49
Once-a-day milking	424	387	294	8
Planting forestry	98	92	77	47
Sum of profits	2,665	2,448	1,910	874
	Simulation results for 2050			
	GHG1 ($28.73/t$CO_2$-e)	GHG2 ($47.8/t$CO_2$-e)	GHG3 ($95.77/t$CO_2$-e)	GHG4 ($191.54/t$CO_2$-e)
No mitigation	1,250	922	450	0
Output approach	125	95	145	155
Reduction in fertiliser use	0	0	298	16
Change in input feed	659	771	314	6
Reduction in cow numbers and same milk production per cow	0	0	–20	–127
Once-a-day milking	401	348	216	0
Planting forestry	94	86	64	21
Sum of profits	2,528	2,222	1,467	71

Table 14. Sheep & beef profits under different GHG price scenarios in 2030 and 2050 for Analysis I, in $ million

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 (\$20.25/tCO_2-e)	GHG2 (\$33.75/tCO_2-e)	GHG3 (\$67.5/tCO_2-e)	GHG4 (\$135/tCO_2-e)
No mitigation	760	681	463	0
Reduction in stocking rates	726	669	527	166
Removal of breeding cows	213	202	176	124
Planting forestry	642	541	311	–9
Sum of profits	2,340	2,094	1,478	281
	Simulation results for 2050			
	GHG1 (\$28.73/tCO2-e)	GHG2 (\$47.8/tCO2-e)	GHG3 (\$95.77/tCO2-e)	GHG4 (\$191.54/tCO2-e)
No mitigation	651	549	243	0
Reduction in stocking rates	603	533	357	0
Removal of breeding cows	185	172	139	73
Planting forestry	522	393	128	–614
Sum of profits	1,962	1,647	867	–541

4.1.4 GHG emissions

Introducing GHG prices for the dairy and sheep & beef sectors reduces GHG emissions from these sectors (Tables 15 and 16). However, the response in terms of the reduction in emissions differs between the two sectors. For instance, for GHG4 in 2030, the dairy sector reduces emissions by 9% compared to 29% for the sheep & beef sector (Tables 8 and 9). In 2050, dairy sector reductions are 15%, while the sheep & beef sector has a 34% reduction in GHG emissions. The larger reduction in GHG emissions from the sheep & beef sector is due to the higher adoption of planting forestry. This option leads to the highest reduction in GHG emissions and reduces the cost burden of higher GHG prices on the sector. The resulting pattern of GHG emissions reductions is driven by profitability between the different dairy and sheep & beef systems in the different regions. Tables 33 and 34 in Appendix 4 show the summary statistics, which include variability of GHG emissions and profits across mitigation options, farming systems and regions for the dairy sector.

The results also show that the emission levels differ across mitigation options and time. For dairy, in the lowest GHG price scenarios GHG emissions are the highest where no mitigation options are adopted, followed by the change in input feed mitigation option. This is because many dairy farmers adopt no mitigation option because its profits are still large under GHG1 (Table 13). The adoption of the output approach increases with increasing GHG prices (i.e. the GHG emissions associated with those who implemented the output approach increases by more than threefold in 2030, and more than twofold in 2050 when comparing GHG4 with GHG1). In 2030, for GHG4 the highest GHG emissions come from the adoption of the output approach and changing input feed mitigation options. The substantial GHG emissions from the output approach are due to the large area allocated for this mitigation option, and because it is still less costly than other mitigation options and generates the largest profits at higher GHG prices.

In 2050 the largest GHG emissions occur from changing input feed and reducing cow numbers while maintaining milk production per cow. The size of GHG emissions reflects the areas that adopt the different mitigation options. Options such as reduced fertiliser use are smaller contributors to GHG emissions because they have low adoption levels due to their cost to GHG mitigation ratio being larger in contrast to other mitigation options.

For the sheep & beef sector, GHG emissions drop by about 20% with GHG1 in both time periods, with this reduction level remaining constant in GHG2 and GHG3 (Table 16). It is not until GHG4 that there is another substantial drop in GHG emissions. With high GHG prices and the resulting high costs from emissions, the sheep & beef sector almost doubles the planting of forestry, and all sheep & beef farms adopt some type of mitigation option (Table 12). Because forestry is integrated into the existing farm system, land is not fully converted to forestry, so there are still GHG emissions associated with the livestock production on the remaining land.

The regional-level analysis for the dairy sector showed that in 2030 imposing higher GHG prices led to a decrease in emissions between 3% and 12%, with the highest relative decrease in Canterbury, Hawke’s Bay, Manawatu–Wanganui, Nelson, Taranaki, and Wellington, while the lowest relative decreases in emissions were in Auckland, Bay of Plenty, Northland, and Waikato. In 2050, imposing higher GHG prices led to a further decrease in emissions, which was estimated at between 6% and 19%. The highest relative decrease is observed in Canterbury, Hawke’s Bay, Manawatu–Wanganui, Taranaki, and Wellington, and the lowest relative decreases in emissions were in the Bay of Plenty and Waikato. In absolute terms, Canterbury, Southland, Taranaki, and Waikato have the largest reductions in GHG emissions (see Tables A9 and A12 in Supplementary Material I).

For the sheep & beef sector, the regional results in 2030 showed that the emissions reduction from higher GHG prices ranged between 0.2% and 23%, with the highest relative decrease in Waikato, followed by Taranaki and Nelson, while the lowest relative decreases in emissions were in Gisborne and Hawke’s Bay. In 2050 the decrease in emissions due to higher GHG prices ranged between 2 and 39%, with the highest relative decreases in Nelson, Marlborough, and Gisborne. In contrast, the lowest relative decreases were in Auckland and Northland. In absolute terms, Canterbury, Hawke’s Bay, Otago, and Waikato have the largest reductions in GHG emissions (see Tables A21 and A24 in Supplementary Material I).

Table 15. Greenhouse gas emissions for dairy with different mitigation options under different GHG price scenarios in 2030 and 2050 for Analysis I, in 1,000 tCO_2-e

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 ($20.25/$tCO_2$-e)	GHG2 ($33.75/$tCO_2$-e)	GHG3 ($67.5/$tCO_2$-e)	GHG4 ($135/$tCO_2$-e)
No mitigation	7,680	7,680	4,214	937
Output approach	1,525	1,525	4,139	4,941
Reduction in fertiliser use	0	0	0	423
Change in supplementary feed	3,681	3,624	4,202	4,797
Reduction in cow numbers and same milk production per cow	0	0	0	1,814
Once-a-day milking	2,751	2,751	2,751	1,390
Planting forestry	445	445	445	445
Sum of GHG emissions	16,081	16,024	15,750	14,747
	Simulation results for 2050			
	GHG1 ($28.73/$tCO_2$-e)	GHG2 ($47.8/$tCO_2$-e)	GHG3 ($95.77/$tCO_2$-e)	GHG4 ($191.54/$tCO_2$-e)
No mitigation	7,680	6,492	4,214	0
Output approach	1,525	1,525	2,841	3,268
Reduction in fertiliser use	0	0	1,315	842
Change in supplementary feed	3,624	4,769	3,725	4,921
Reduction in cow numbers and same milk production per cow	0	0	252	4,318
Once-a-day milking	2,751	2,751	2,751	0
Planting forestry	445	445	445	445
Sum of GHG emissions	16,024	15,982	15,543	13,794

Table 16. Greenhouse gas emissions for sheep & beef with different mitigation options under different GHG price scenarios in 2030 and 2050 for Analysis I, in 1,000 tCO_2

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 ($20.25/tCO2-e)	GHG2 ($33.75/tCO2-e)	GHG3 ($67.5/tCO2-e)	GHG4 ($135/tCO2-e)
No mitigation	5,823	5,823	5,141	0
Reduction in stocking rates	4,205	4,205	4,205	2,235
Removal of breeding cows	770	770	770	770
Planting forestry	7,467	7,467	8,081	13,333
Sum of GHG emissions	18,265	18,265	18,197	16,339
	Simulation results for 2050			
	GHG1 ($28.73/tCO2-e)	GHG2 ($47.8/tCO2-e)	GHG3 ($95.77/tCO2-e)	GHG4 ($191.54/tCO2-e)
No mitigation	5,339	5,339	3,095	0
Reduction in stocking rates	3,678	3,678	3,678	0
Removal of breeding cows	692	692	692	692
Planting forestry	6,706	6,706	8,726	12,895
Sum of GHG emissions	16,416	16,416	16,191	13,587

4.2 Analysis I: Wider economic effects

4.2.1 Summary of results

To explore the wider impacts of the GHG price effects, we specifically analyse the outcomes of two scenarios, GHG1 and GHG4, on the entire economy of New Zealand in 2050 using ESSAM. The model closure assumptions are given in Appendix 2. The main results show that the GHG1 scenario has a reduction in emissions from the dairy and sheep & beef sectors of 1.7 Mt CO_2-e relative to the reference case in 2050. The GHG4 scenario has an assumed reduction of 8.0 Mt.

4.2.2 Macroeconomic results

The key results for the GHG1 and GHG4 scenarios are shown in Table 17. The former has very small macroeconomic effects. There is 0.1% reduction in GDP, but the slight lift in the terms of trade is enough to prevent a reduction in New Zealand's real gross national disposable income (RGNDI) and private consumption (macroeconomic closure rules are outlined in a separate section below).

Although the exogenous change in agricultural methane and nitrous oxide emissions is 4.5 Mt, the price on emissions impairs the competitiveness of agricultural exports, leading to a reduction in agricultural output, which in turn lowers agricultural emissions by 5.1 Mt. Essentially, the modelling tells us that not all pastoral farming can generate an economic return if there is a price on agricultural GHG emissions. The decline in total emissions is almost the same at 5.2 Mt, so a given national emissions target could be achieved with a slightly lower C price if agricultural emissions are priced and if the proposed mitigation options are implemented.

Table 17. Macroeconomic results for 2050: change relative to the reference case for Analysis I

	GHG1 (\$28.73/tCO_2-e)	**GHG4 (\$191.54/tCO_2-e)**
Indicators	**% Δ on associated reference case**	
Emissions price	\$28.73	\$191.54
Private consumption	0.0%	0.4%
Exports	–0.5%	–2.3%
Imports	–0.1%	–0.3%
GDP	–0.1%	–0.2%
RGNDI[14]	0.0%	0.3%
Terms of trade	0.4%	2.0%
Real wage rate	–0.2%	–1.0%
	CO_2-e (Mt)	
Gross emissions	–5.2	–15.1
Agricultural CH_4 & N_2O	–5.1	–12.5

Not surprisingly, the GHG4 scenario has larger impacts, but the general story is the same. Exports and GDP decline, enabling resources to flow instead into private consumption. Hence, the macroeconomic impacts of extending an existing price on emissions to apply to agricultural methane and nitrous oxide emissions, and securing the associated reduction in on-farm emissions, can be negative (using GDP as the metric) or positive (using RGNDI as the metric).

Pastoral agriculture is a relatively efficient user of labour and capital. Many other industries are less productively efficient, so GDP declines if agricultural output declines. However, economic welfare relies on allocative efficiency as well as productive efficiency. If an industry (or, more accurately, parts of it) can no longer supply goods and services at prices that reflect all its resource input costs, and at a price that consumers are willing to pay, it is better for those resources to flow into other industries, even if their productive efficiency is lower. One may be the best in the world at producing something, but that is of little use if consumers prefer to buy something else.

In GHG4 the assumed exogenous reduction in agricultural methane and nitrous oxide emissions is 9.5 Mt, but the reduction in agricultural output and its effects on the wider economy increase this to 12.5 Mt. Total emissions decline by a greater amount (15.1 Mt).

[14] Real Gross National Disposable Income is GDP adjusted for net offshore factor payments (such as interest and dividend flows) and changes in the terms of trade.

So, again, the message is that pricing agricultural emissions can lower the burden of reducing emissions that is faced by other industries.

In a case where agricultural GHG emissions are exempt from GHG emission pricing and the proposed on-farm mitigation measures are not implemented, the emissions price would have to be about \$1,000/tCO_2-e (that would need to be levied on emissions from industry and services) to reach the same level of GHG emission abatement achieved with the GHG4 price scenario of \$191.54/tCO_2-e. In such a situation, the GDP is lower by 6% than in the reference case.

4.2.3 Effects on agriculture and forestry

The effects on gross output and employment in the model's four agricultural industries and the forestry industry are shown in Table 18. All the agricultural industries experience contractions in output as a result of a price being imposed on GHG emissions. Sheep & beef farming is hit hardest, even though the exogenous emission mitigation measures are more pronounced than in dairy farming.

Horticulture and other farming (e.g. deer and poultry) also see declines in output: both industries emit nitrous oxide, and other farming also emits methane, albeit nowhere near the intensity per unit of output that occurs in the dairy and sheep & beef sectors. Nonetheless, they are still negatively affected by an emissions price. They have limited ability to reduce emissions by reducing fertiliser use. The only other alternative is curtailing output. It should be taken into account that we do not consider land-use change, in which case the horticultural area might increase instead of dairy.

In contrast, the forestry industry experiences modest growth as its relative competitiveness has improved. There is easily enough land released from agriculture to be taken up by forestry, so the model may understate its growth, even allowing for the likelihood that not all of the land is suitable for forestry.

In all cases the reductions in employment in agriculture are slightly smaller than the reductions in output, implying a marginal increase in labour intensity. This is a consequence of the fall in the real wage rate (see Table 17) that is required to maintain employment at the same level as the reference case.

Table 18. Gross output and employment in agriculture and forestry in 2050: change relative to the reference case for Analysis I

	% Δ on respective reference case			
	GHG1 ($28.73/tCO$_2$-e)		GHG4 ($191.54/tCO$_2$-e)	
Land use	**Output**	**Employment**	**Output**	**Employment**
Horticulture	–0.9%	–0.7%	–4.9%	–4.2%
Sheep & beef	–2.5%	–1.9%	–12.7%	–10.4%
Dairy	–1.8%	–1.6%	–9.2%	–8.4%
Other farming	–1.3%	–1.0%	–6.9%	–5.7%
Forestry	0.2%	0.4%	1.6%	1.9%

4.2.4 Results for GHG2 and GHG3 scenarios

With regard to the ESSAM model results for emissions reduction price scenarios GHG2 and GHG3, the results of GHG2 are almost identical to the scenario GHG1, but with slightly lower emission levels and a higher emission price. The macroeconomic results would be within the error margin of the GHG1 scenario. The specification of the GHG3 scenario suggests its macroeconomic effects would fall roughly a quarter of the way between those for the GHG1 and GHG4 prices.

4.2.5 Caveat

The exogenously imposed reductions in agricultural GHG emissions are modelled without any associated costs. It is therefore possible that the economic effects are understated. However, as discussed in section 3, some measures may theoretically be costless, although there could be other barriers to take-up.

5 Analysis II: Adding a new dairy mitigation option

We now consider an additional mitigation option for dairy beyond those in Analysis I. In this mitigation option, cow numbers are reduced but productivity (milk production per cow) increases. The full list of dairy mitigation options included in Analysis II is outlined in Table 5 (section 2.3). The mitigation options for sheep & beef are the same as in Analysis I.

5.1 Analysis II: Agricultural sector impacts based on NZFARM modelling

NZFARM modelling indicates a large portion of the dairy sector takes up the new mitigation option (i.e. reduced cow numbers at increased milk production per cow) at the lower GHG prices. Approximately 87% of the dairy area has adopted that mitigation option at GHG1 (derived from Table 22). The remaining dairy area is taken up by the output approach (c. 7%), once-a-day milking (c. 3%), and partial planting of forestry (c. 3%). This pattern does not change much as GHG prices increase. At GHG4 there is a further increase in uptake of the new mitigation option, a reduction in the output approach, and no change in the partial planting of forestry, and there is no longer any once-a-day milking (Table 22).

Results also suggest that all dairy land adopts mitigation options (Table 22) for all GHG prices in both the 2030 and 2050 periods. The large move to the new mitigation option is due to it not only reducing GHG emissions but also increasing profitability before accounting for GHG prices, and only reducing profitability when GHG prices are incorporated.

In terms of GHG emissions, there is an 18% reduction in GHG emissions with the new mitigation option at GHG1 (Table 19). This is considerably larger than the approximately 1% reduction from Analysis I. At GHG4, the GHG emission reduction is 19% for 2030 and 2050, compared to a 9% and 15% reduction in GHG emissions for 2030 and 2050, respectively, in Analysis I. This indicates that emissions can be reduced considerably more at lower prices in Analysis II than in Analysis I.

At the same time, the impact on profits increases at higher GHG prices. Profits decrease between 7% (for GHG1) and 59% (for GHG4) in 2030, and between 11% (for GHG1) and 84% (for GHG4) in 2050. The relatively large decrease in profits, even under low GHG prices (i.e. GHG1), is due to some dairy systems having high GHG emissions and low profitability. GHG prices therefore increase costs for the dairy sector and reduce its profits.

The continuing reduction in profits with almost no further decrease in GHG emissions as GHG prices rise is due to the bulk of the mitigation options being taken up in GHG1. As GHG prices rise there are no other mitigation options with higher profitability available to the sector, and the dairy sector is required to pay these higher prices with no further ability to reduce their emissions in our analysis. While not modelled here, dairy farmers in this situation may consider other management changes, such as totally changing land use (e.g. shifting from dairy to horticultural farming) or adopting different technological options that boost farm productivity to avoid the financial losses associated with high GHG prices. Our analysis does, however, highlight the implications of pricing biological emissions given the suite of mitigation options currently available to the dairy and sheep & beef sectors.

The regional results also show which dairy systems and regions are likely to be most affected financially when faced with GHG pricing under these general conditions (see Supplementary Material II). For example, in 2050 with the highest GHG price (GHG4), the dairy sector in Canterbury, Marlborough, Nelson, Tasman, and the West Coast has losses even after implementing mitigation options (Table B8 in Supplementary Material II). Under such GHG prices, the dairy profit trend across regions is similar to that in Analysis I; however, the magnitude of profit reduction is lower in Analysis II (compare Table B8 in in Supplementary Material II with Table A8 in Supplementary Material I).

There is no difference in the results for the sheep & beef sector between Analysis I and Analysis II (Table 20 and Table 9), as the same mitigation options were considered for the sector in both analyses.

Considering all land uses (Table 21), GHG emissions reduce between 19% and 24% in 2030 and between 19% and 26% in 2050 as a response to the pricing of GHG emissions and mitigation options. The corresponding reduction in profits from all sectors is between 5% and 44% in 2030 and between 7% and 57% in 2050. However, the impacts of GHG prices on agricultural and forestry land uses should be treated with caution, as we do not consider land-use change or additional technological changes that may improve agricultural productivity, which might lead to different outcomes. From our analysis, however, we can isolate the effects of pricing GHG biological emissions given the suite of mitigation options currently available (Analysis I) and with an additional mitigation option that not only reduces GHG emissions but also increases productivity in the dairy sector (Analysis II).

Table 19. Summary results for dairy changes under different GHG prices with respect to the reference case for Analysis II

Scenario	Profit, in $ million	GHG emissions, in 1,000 tCO_2-e
	Simulation results for 2030	
Reference case	2,940	16,279
GHG1 ($20.25/$tCO_2$-e)	–7%	–18%
GHG2 ($33.75/$tCO_2$-e)	–13%	–18%
GHG3 ($67.5/$tCO_2$-e)	–28%	–18%
GHG4 ($135/$tCO_2$-e)	–59%	–19%
	Simulation results for 2050	
Reference case	2,940	16,279
GHG1 ($28.73/$tCO_2$-e)	–11%	–18%
GHG2 ($47.88/$tCO_2$-e)	–20%	–18%
GHG3 ($95.77/$tCO_2$-e)	–41%	–19%
GHG4 ($191.54/$tCO_2$-e)	–84%	–19%

Table 20. Summary results for sheep & beef changes under different GHG prices with respect to the reference case for Analysis II

Scenario	Profit, in $ million	GHG emissions, 1,000 tCO_2-e
	Simulation results for 2030	
Reference case	2,577	23,072
GHG1 ($20.25/$tCO_2$-e)	–9%	–21%
GHG2 ($33.75/$tCO_2$-e)	–19%	–21%
GHG3 ($67.5/$tCO_2$-e)	–43%	–21%
GHG4 ($135/$tCO_2$-e)	–89%	–29%
	Simulation results for 2050	
Reference case	2,313	20,635
GHG1 ($28.73/$tCO_2$-e)	–15%	–20%
GHG2 ($47.88/$tCO_2$-e)	–29%	–20%
GHG3 ($95.77/$tCO_2$-e)	–63%	–22%
GHG4 ($191.54/$tCO_2$-e)	–123%	–34%

Table 21. Summary results considering all agricultural and forestry land-use changes under different GHG prices with respect to the reference case for Analysis II

Scenario	Profits, in $ million	GHG emissions, 1,000 tCO_2-e
	Simulation results for 2030	
Reference case	9,224	41,281
GHG1 ($20.25/tCO2-e)	–5%	–19%
GHG2 ($33.75/tCO2-e)	–9%	–19%
GHG3 ($67.5/tCO2-e)	–21%	–19%
GHG4 ($135/tCO2-e)	–44%	–24%
	Simulation results for 2050	
Reference case	9,362	38,844
GHG1 ($28.73/tCO2-e)	–7%	–19%
GHG2 ($47.88/tCO2-e)	–13%	–19%
GHG3 ($95.77/tCO2-e)	–28%	–19%
GHG4 ($191.54/tCO2-e)	–57%	–26%

5.1.1 Land-use and mitigation options

With the implementation of GHG prices for biological emissions, dairy farmers adopt those mitigation options that maximise their profits while reducing GHG emissions. In Analysis II, the introduction of a dairy mitigation option that maintains farm profits while reducing GHG emissions (i.e. reduction in cow numbers and increase in milk production per cow) resulted in a large uptake of that mitigation option, even with the lowest GHG price (GHG1) (Table 22). In particular, dairy farms in Bay of Plenty, Canterbury, and Waikato use only this option (Table B1 in Supplementary Material II). Although the dairy sector in other regions diversifies its mitigation practices, it still allocates most of its land area to reduction in cow numbers and increase in milk production per cow. Dairy system 4 has the largest area under this mitigation option, which is on about 25% of the total dairy area.

At the request of BERG, there was no constraint placed on the uptake of any dairy mitigation options in this analysis, so the model shows a rapid move to this mitigation option even at low GHG prices. At high GHG prices there are only minor changes in the adoption rates, primarily because the comparative advantage in the cost-effectiveness of certain mitigation options does not change. For GHG4 there is a small increase in the uptake of the new mitigation option at the expense of the output approach and once-a-day milking. Table 22 provides details for the simulated area of mitigation options adopted by the dairy sector. The results on adoption of mitigation options by the sheep & beef sector are the same as in Analysis I, as the same mitigation options were considered for this sector in both analyses (Table 23). Tables 33–35 in Appendix 4 show the data on GHG emissions and profits with each mitigation option for the dairy and sheep & beef sectors (with the latter unchanging in Analysis II).

When comparing dairy responses across 2030 and 2050 (Table 22), the 87% uptake (2,007,000 ha) of the new mitigation option is the same in both time periods for GHG1 and

GHG2, with only a minor difference for GHG3. The GHG3 difference involves a full shift from once-a-day milking to the new mitigation option. The amount of land in the other mitigation options is constant for both the 2030 and 2050 periods. Although constant between periods, GHG4 has the largest change in the uptake of mitigation options in the dairy sector. For example, in 2050 under GHG4, adoption of the new mitigation option increases to 92% of the dairy land area, while the uptake of the output approach option falls to about 4%. The increase comes from shifting the area that was allocated under GHG1 to once-a-day milking in Auckland and Northland, and the area that was allocated to the output approach in Otago and Southland to reduction in cow numbers and increase in milk production per cow (Tables B1–B4 in Supplementary Material II).

These increases are due to the fact that at the higher GHG prices, once-a-day milking and the output approach become less profitable compared to the new mitigation option. Planting forestry on part of a dairy farm is more profitable than other mitigation options for all GHG prices for dairy system 2 in Marlborough, Nelson, Tasman, and the West Coast, where there is likely to be more areas of marginal dairy land. As a result, there is no once-a-day milking, a decrease in the output approach, and forestry planting remains the same at about 3% of dairy area. Also, the dairy sector in Marlborough, Nelson, Tasman, and the West Coast has the same area, dairy systems, and intensities/levels for mitigation options across the GHG prices. For Gisborne, Hawke's Bay, and Manawatu–Wanganui, Taranaki, and Wellington the types and area of mitigation options remain the same across GHG prices, but the intensities/levels of these mitigations increase with the increase in GHG prices.

The large uptake in the new mitigation option is likely to be less in reality than is shown in our modelling. This is due to the heterogeneity across the dairy sector in being able to select stock for higher productivity, the widespread availability of stock with higher productivity, and/or other barriers that farmers may have to implementing or achieving such an option. However, our modelling does show what the scale of GHG emissions reductions could be and the corresponding financial implications of pricing biological GHG emission if such a mitigation option were widely available and taken up. For other mitigation options, such as reducing fertiliser use, changing supplementary feed, and reducing cow numbers, they are not adopted because they have a lower profitability with GHG prices than the other mitigation options.

Table 22. Area of mitigation options adopted by dairy under different GHG price scenarios in 2030 and 2050 for Analysis II with the new mitigation option, in 1,000 ha[15]

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 ($20.25/t$CO_2$-e)	GHG2 ($33.75/t$CO_2$-e)	GHG3 ($67.5/t$CO_2$-e)	GHG4 ($135/t$CO_2$-e)
No mitigation	0	0	0	0
Output approach	153	153	153	100
Reduction in fertiliser use	0	0	0	0
Change in supplementary feed	0	0	0	0
Reduction in cow numbers and same milk production per cow	0	0	0	0
Once-a-day milking	60	60	60	0
Planting forestry	79	79	79	79
Reduction in cow numbers and increase in milk production per cow	2,007	2,007	2,007	2,120
	Simulation results for 2050			
	GHG1 ($28.73/t$CO_2$-e)	GHG2 ($47.8/t$CO_2$-e)	GHG3 ($95.77/t$CO_2$-e)	GHG4 ($191.54/t$CO_2$-e)
No mitigation	0	0	0	0
Output approach	153	153	153	100
Reduction in fertiliser use	0	0	0	0
Change in supplementary feed	0	0	0	0
Reduction in cow numbers and same milk production per cow	0	0	0	0
Once-a-day milking	60	60	0	0
Planting forestry	79	79	79	79
Reduction in cow numbers and increase in milk production per cow	2,007	2,007	2,067	2,120

[15] Note that in some instance the results look identical due to the rounding of the numbers.

Table 23. Area of mitigation options adopted by sheep & beef under different GHG price scenarios in 2030 and 2050 for Analysis II, in 1,000 ha

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 ($20.25/t$CO_2$-e)	GHG2 ($33.75/t$CO_2$-e)	GHG3 ($67.5/t$CO_2$-e)	GHG4 ($135/t$CO_2$-e)
No mitigation	1,606	1,606	1,398	0
Reduction in stocking rates	2,321	2,321	2,321	1,262
Removal of breeding cows	391	391	391	391
Planting forestry	3,502	3,502	3,709	6,167
	Simulation results for 2050			
	GHG1 ($28.73/t$CO_2$-e)	GHG2 ($47.8/t$CO_2$-e)	GHG3 ($95.77/t$CO_2$-e)	GHG4 ($191.54/t$CO_2$-e)
No mitigation	1,471	1,471	746	0
Reduction in stocking rates	2,030	2,030	2,030	0
Removal of breeding cows	351	351	351	351
Planting forestry	3,177	3,177	3,902	6,678

5.1.2 Profits

In general, profits decrease when GHG prices are placed on biological GHG emissions from agriculture. In 2030 dairy profits are estimated to decrease by 7%, 13%, 28%, and 59% when imposing GHG1, GHG2, GHG3, and GHG4, respectively. In this period, the dairy sector in Marlborough has the largest relative profit decrease from GHG1 price to GHG4 (80% profit decrease), followed by dairy in Nelson, Tasman, and the West Coast (all have a 79% profit decrease). Dairy system 3 has the largest profit decrease in absolute values, which is about $638 million when taking into account the difference in profits in GHG1 and GHG4. The lowest profit decrease is in Otago and Southland (both have 47% profit decrease) (Tables B5 and B6 in Supplementary Material II).

In 2050 dairy profits fall by 11% (GHG1), 20% (GHG2), 41% (GHG3), and 84% (GHG4) (Table 19). The largest relative dairy profit decreases (when comparing profits in GHG4 with GHG1) are in Marlborough, Tasman, and the West Coast (all have a 120% profit decrease), followed by Nelson (119% profit decrease) and Canterbury (115% profit decrease) (Tables B7 and B8 in Supplementary Material II). The least negatively affected dairy profits are in Otago and Southland (both have a 68% profit decrease). This is similar to Analysis I, where profits decrease as GHG emissions prices increase. However, the magnitude of the reduction in profit is less than in Analysis I. This is due to the new mitigation option not only reducing GHG emissions but also having a smaller impact on profits[16] for most dairy systems.

The new mitigation option provides the largest share of profits under all GHG prices in 2030 and 2050, ranging between 92% and 95% in 2030 and between 92% and 99% in 2050 (Table 24). Already with a low GHG price (GHG1), the dairy sector in Bay of Plenty, Canterbury, and Waikato generates its profits only from reduction in cow numbers and increase in milk production per cow, because this option is the most profitable one in these regions (Tables B5 and B7 in Supplementary Material II). With such a GHG price, other regions (in addition to the new mitigation option) also have the output approach and planting forestry, and thus generate profits from these options as well.

At the highest GHG price in 2050, about 4% of dairy area (Table 22) has taken up the output approach despite experiencing losses of $15 million from this mitigation option. For instance, dairy system 3 in Manawatu–Wanganui and Taranaki has losses of $5.9 and $6.7 million when adopting the output approach (Table B8 in Supplementary Material II). That option lowers profits less than other available mitigation options under GHG4 for dairy system 3 in these regions.

Considering all mitigation options adopted across regions with GHG4 price in 2050, planting forestry is the only option that does not have financial losses, and it is adopted in Marlborough, Nelson, Tasman, and the West Coast. While not modelled in this analysis, dairy farmers that have financial losses may consider other management changes not included here, such as totally changing land use (e.g. shifting from dairy to horticultural farming) or adopting different technological options that boost farm productivity to avoid the financial losses associated with high GHG prices.

Since no mitigation options changed, the sheep & beef profits are the same as in Analysis I (Table 25).

[16] Without accounting for the pricing of GHG emissions, this mitigation option increases farm profits (Table 34 in Appendix 4) while markedly reducing GHG emissions (Table 33 in Appendix 4). When biological GHG emissions are priced, there is a reduction in farm profits.

Table 24. Dairy profits under different GHG price scenarios in 2030 and 2050 for Analysis II with the new mitigation option, in $ million

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 ($20.25/t$CO_2$-e)	GHG2 ($33.75/t$CO_2$-e)	GHG3 ($67.5/t$CO_2$-e)	GHG4 ($135/t$CO_2$-e)
No mitigation	0	0	0	0
Output approach	84	74	47	10
Reduction in fertiliser use	0	0	0	0
Change in supplementary feed	0	0	0	0
Reduction in cow numbers and same milk production per cow	0	0	0	0
Once-a-day milking	47	42	30	0
Planting forestry	98	92	77	47
Reduction in cow numbers and increase in milk production per cow	2,504	2,345	1,949	1,155
Sum of profits	2,733	2,553	2,104	1,212
	Simulation results for 2050			
	GHG1 ($28.73/t$CO_2$-e)	GHG2 ($47.8/t$CO_2$-e)	GHG3 ($95.77/t$CO_2$-e)	GHG4 ($191.54/t$CO_2$-e)
No mitigation	0	0	0	0
Output approach	78	63	25	-15
Reduction in fertiliser use	0	0	0	0
Change in input feed	0	0	0	0
Reduction in cow numbers and same milk production per cow	0	0	0	0
Once-a-day milking	44	37	0	0
Planting forestry	94	86	64	22
Reduction in cow numbers and increase in milk production per cow	2,404	2,179	1,639	463
Sum of profits	2,620	2,365	1,728	469

Table 25. Sheep & beef profits under different GHG price scenarios in 2030 and 2050 for Analysis II, in $ million

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 (\$20.25/tCO_2-e)	GHG2 (\$33.75/tCO_2-e)	GHG3 (\$67.5/tCO_2-e)	GHG4 (\$135/tCO_2-e)
No mitigation	760	681	463	0
Reduction in stocking rates	726	669	527	166
Removal of breeding cows	213	202	176	124
Planting forestry	642	541	311	–9
Sum of profits	2,340	2,094	1,478	281
	Simulation results for 2050			
	GHG1 (\$28.73/tCO_2-e)	GHG2 (\$47.8/tCO_2-e)	GHG3 (\$95.77/tCO_2-e)	GHG4 (\$191.54/tCO_2-e)
No mitigation	651	549	243	0
Reduction in stocking rates	603	533	357	0
Removal of breeding cows	185	172	139	73
Planting forestry	522	393	128	–614
Sum of profits	1,962	1,647	867	–541

5.1.3 GHG emissions

The addition of the mitigation option that reduces cow numbers and increases milk production per cow has large implications for the reduction in GHG emissions from the dairy sector. This mitigation option can reduce GHG emissions by 18%, even at the lowest GHG prices, compared to the reference case (Table 19). This is a large difference to the 1–2% GHG emission reduction in Analysis I. With low GHG price (GHG1), the regions that have the most GHG decrease in comparison to the reference case are Bay of Plenty, Canterbury, and Waikato, because the dairy sector in these regions adopts on their entire land area the mitigation option that reduces cow numbers and increases the milk production per cow (Table B1 in Supplementary Material II).

At higher GHG prices, GHG emissions are only reduced by 19%, indicating that most of the uptake of mitigation options is achieved at lower GHG prices. With GHG4 price the highest relative GHG reductions are in Auckland and Northland (5% decrease; Table B12 in Supplementary Material II), as dairy ceases using once-a-day milking on its large land area and instead adopts reduction in cow numbers and increase in milk production per cow (Table B4 in Supplementary Material II).

The total GHG emissions across options can be seen in Table 26, which is proportional to the area in Table 22. The largest share of GHG emissions is from land that adopts the new mitigation option, which is between 88% and 93% of total emissions in 2030 and 2050.

The larger decrease in GHG emissions in Analysis II than in Analysis I (see section 4.1.4) reflects the higher profitability of the new mitigation option compared to most other mitigation options at different GHG prices. Appendix 4 shows the data on variability of GHG emissions across mitigation options, farming systems, and regions.

The sheep & beef GHG emissions are the same as in Analysis I and are reproduced in Table 27.

Table 26. Greenhouse gas emissions for dairy with different mitigation options under different GHG price scenarios in 2030 and 2050 for Analysis II with the new mitigation option, in 1,000 tCO_2

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 ($20.25/$tCO_2$-e)	GHG2 ($33.75/$tCO_2$-e)	GHG3 ($67.5/$tCO_2$-e)	GHG4 ($135/$tCO_2$-e)
No mitigation	0	0	0	0
Output approach	782	782	782	446
Reduction in fertiliser use	0	0	0	0
Change in supplementary feed	0	0	0	0
Reduction in cow numbers and same milk production per cow	0	0	0	0
Once-a-day milking	352	352	352	0
Planting forestry	445	445	445	445
Reduction in cow numbers and increase in milk production per cow	11,731	11,731	11,731	12,247
Sum of GHG emissions	13,310	13,310	13,310	13,138
	Simulation results for 2050			
	GHG1 ($28.73/$tCO_2$-e)	GHG2 ($47.8/$tCO_2$-e)	GHG3 ($95.77/$tCO_2$-e)	GHG4 ($191.54/$tCO_2$-e)
No mitigation	0	0	0	0
Output approach	782	782	767	425
Reduction in fertiliser use	0	0	0	0
Change in supplementary feed	0	0	0	0
Reduction in cow numbers and same milk production per cow	0	0	0	0
Once-a-day milking	352	352	0	0
Planting forestry	445	445	445	445
Reduction in cow numbers and increase in milk production per cow	11,731	11,731	12,021	12,247
Sum of GHG emissions	13,310	13,310	13,233	13,117

Table 27. Greenhouse gas emissions for sheep & beef with different mitigation options under different GHG price scenarios in 2030 and 2050 for Analysis II, in 1,000 tCO_2

Mitigation option	GHG emission price scenario			
	Simulation results for 2030			
	GHG1 ($20.25/$tCO_2$-e)	GHG2 ($33.75/$tCO_2$-e)	GHG3 ($67.5/$tCO_2$-e)	GHG4 ($135/$tCO_2$-e)
No mitigation	5,823	5,823	5,141	0
Reduction in stocking rates	4,205	4,205	4,205	2,235
Removal of breeding cows	770	770	770	770
Planting forestry	7,467	7,467	8,081	13,333
Sum of GHG emissions	18,265	18,265	18,197	16,339
	Simulation results for 2050			
	GHG1 ($28.73/$tCO_2$-e)	GHG2 ($47.8/$tCO_2$-e)	GHG3 ($95.77/$tCO_2$-e)	GHG4 ($191.54/$tCO_2$-e)
No mitigation	5,339	5,339	3,095	0
Reduction in stocking rates	3,678	3,678	3,678	0
Removal of breeding cows	692	692	692	692
Planting forestry	6,706	6,706	8,726	12,895
Sum of GHG emissions	16,416	16,416	16,191	13,587

5.2 Analysis II: Wider economic effects

Table 28 shows the macroeconomic results for Analysis II. For the GHG1 price in Analysis II, the macroeconomic effects are very similar to Analysis I, with only the change in exports differing by more than 0.1% (compare Table 28 and Table 17). The only difference between them in terms of input shocks is that in Analysis II the imposed reduction in dairy farm emissions is greater by about 3 Mt as a result of more milk output per cow.

The reduction in emissions is imposed without cost so there are no effects on other industries. Such effects would occur if the scenarios were run with a national emissions target, as the greater reduction in Analysis II means that a given target could be achieved with a lower emissions price – which would affect the whole economy.

The exogenous productivity improvement in dairy farming (more milk per cow), which enhances its competitiveness, somewhat offsets the effect of the emissions price. In GHG4 in Analysis II, the macroeconomic results are again similar to those in GHG4 in Analysis I (compare Table 28 and Table 17), with the most favourable effect being on exports – a consequence of the productivity improvement in dairy farming.

From an input perspective, the difference in specified dairy emissions between GHG4 prices in Analysis I and Analysis II is much smaller than the difference between GHG1 prices in Analysis I and Analysis II. This means that the production-boosting effect has a more noticeable effect on emissions. In particular, between GHG1 prices in Analysis I and

Analysis II the reduction in emissions for agriculture increases by almost 50%, but between GHG4 prices in Analysis I and Analysis II the reduction increases by less than 5%.

Table 28. Macroeconomic results for 2050: change relative to the reference case for Analysis II

	GHG1-II ($28.73/t$CO_2$-e)	GHG4-II ($191.54/t$CO_2$-e)
Indicator	**% Δ on associated reference case**	
Emissions price	$28.73	$191.54
Private consumption	0.0%	0.3%
Exports	–0.2%	–2.0%
Imports	–0.0%	–0.3%
GDP	–0.0%	–0.2%
RGNDI[17]	0.0%	0.3%
Terms of trade	0.1%	1.8%
Real wage rate	–0.1%	–0.9%
	CO_2-e (Mt)	
Gross emissions	–7.5	–13.0
Agricultural CH_4 & N_2O	–7.5	–12.9

Table 29 shows the effects on gross output and employment in the model's four agricultural industries and the forestry industry. The results of Analysis II are similar to those for Analysis I, with minor differences is in the magnitudes of outcomes (compare Table 29 and Table 18). All the agricultural land uses have reductions in output because of the GHG price being imposed, as in Analysis I. Sheep & beef is hit harder than dairy, although the exogenous emission mitigation measures are more pronounced than in dairy farming. In contrast, the output from forestry and employment has increased as a result of the increase in forestry area.

Table 29. Gross output and employment in agriculture and forestry in 2050: change relative to the reference case for Analysis II

	% Δ on respective reference case			
	GHG1-II ($28.73/t$CO_2$-e)		GHG4-II ($191.54/t$CO_2$-e)	
Land use	**Output**	**Employment**	**Output**	**Employment**
Horticulture	–0.9%	–0.7%	–4.8%	–4.2%
Sheep & beef	–2.0%	–1.6%	–12.3%	–10.1%
Dairy	–0.2%	0.0%	–7.7%	–6.8%
Other farming	–1.1%	–0.8%	–6.7%	–5.5%
Forestry	0.2%	0.2%	1.5%	1.8%

[17] Real Gross National Disposable Income is GDP adjusted for net offshore factor payments (such as interest and dividend flows) and for changes in the terms of trade.

6 Ecosystem service costs and benefits from pricing GHG emissions

Pricing GHG emissions sends a signal to landowners to lower their GHG emissions. This incentivises landowners to change the way they manage their land. The management responses by landowners will reduce GHG emissions, but are also likely to affect other parts of the environment and society.

To estimate the wider effects of pricing GHG emissions, an ecosystem services framework was used. Ecosystem services are the benefits that nature provides and are typically categorised as provisioning, regulating, cultural, and supporting services (Table 30).

Table 30. Ecosystem service categories

Provisioning ***Products obtained from ecosystems***	**Regulating** ***Benefits from regulation of ecosystem processes***	**Cultural** ***Non-material benefits obtained from ecosystems***
Food and fibre Freshwater Wild foods Fuel Biochemical, natural medicines & pharmaceuticals Genetic resources Ornamental resources	Air quality maintenance Climate regulation Water regulation Water purification & waste treatment Erosion control Disease regulation Biological control Pollination Storm protection	Recreation & ecotourism Ethical & spiritual values: aesthetic values cultural heritage values cultural diversity sense of place spiritual & religious values social relations. Inspirational & educational values: inspiration knowledge systems
Supporting ***Services necessary for the production of all other ecosystem services***		
Nutrient and water cycling Primary production (e.g. photosynthesis) Production of atmospheric oxygen	Provisioning of habitat Soil formation and retention	

For this assessment we used a rapid ecosystem service approach that involves the following.

- Identify which ecosystem services are relevant to the decision being considered (i.e. the pricing of GHG emissions): the questions in Table 31 are used to determine whether the pricing of GHG emissions depends on an ecosystem service and/or has an impact on an ecosystem service. If the pricing of GHG emissions depends or impacts on an ecosystem service then it is considered relevant. An ecosystem service where the effect is determined to be uncertain or unlikely is not considered relevant for this assessment, even though they may be.
- Use the uptake of mitigation options in response to the pricing of GHG emissions to estimate the magnitude of expected effects.

- This assessment is largely a qualitative assessment. Some effects are derived directly from the economic analysis, with the remainder inferred from the extent and type of mitigation options adopted in response to the pricing of GHG emissions. A summary of the expected wider costs and benefits is outlined in Table 32.

Table 31. Questions used to identify the ecosystem services to consider when pricing GHG emissions

Dependency	Impacts
Does this ecosystem service enable or enhance conditions to successfully implement a GHG emissions price for biological emissions?	Does the pricing of biological GHG emissions affect the quantity or quality of this ecosystem service? If yes, Will pricing GHG emissions have a positive or negative impact? Does the impact of pricing GHG emissions limit or enhance the ability of others to benefit from this service?

Note: business questions come directly from WRI (2012), while council questions are adapted from WRI (2012), Rangathan et al. (2008) and our knowledge of government decision-making.

While the magnitude of how wider ecosystem services are affected by pricing GHG emissions is largely not quantified, in many instances the impact on the regulating services is expected to be positive. In other words, the mitigation options, particularly additional forested areas, improve the flow of the regulating services. The exception is any negative effect on air quality maintenance services of increased pine pollen production from the additional (pine) forest area. Water yield is also expected to decrease with more forested areas, which will affect water regulation services.

Food and fibre production are directly affected by pricing GHG emissions, and the impact tends to be negative due to the estimated decrease in overall livestock production levels resulting from the adoption of mitigation options. The magnitude of these impacts increases as GHG prices increase.

A number of impacts are also indirect, meaning it is the change in another ecosystem service that causes an ecosystem service to be affected. For instance, some of the expected change in wild foods and recreation is related to changes in water purification, water regulation, and erosion control services. Given these regulating services are expected to improve, then wild foods and recreation benefits are also expected to improve.

Some impacts may also be positive or negative depending on a person's preference and/or the location of some of these changes. The impact on aesthetic values (e.g. views) will differ based on the location of new forested areas and how the community/individuals regard the aesthetic value of pine forests.

Some of the effects are also uncertain and will depend on the mitigation option, location of uptake of a mitigation option, and external factors such as processing capacity. For example, where the forestry mitigation option is taken up, there is potential not only to increase timber production but also to increase biomass fuel production. This benefit, however, will depend on whether there is any biomass fuel processing capacity to utilise the additional resource, as well as the size and reliability of biomass supply.

Table 32. Rapid assessment of costs and benefits (based on ecosystem services) associated with pricing GHG emissions

ES cat.	Ecosystem service	Ecosystem service descriptors	Relevance	Impact and/or dependency	Expected effects of a GHG price			
					GHG1	GHG2	GHG3	GHG4
Provisioning (products obtained from ecosystems)	Food	e.g. milk, meat, crops, fish	Yes	Pricing biological GHG emissions is predicated on biological emissions so depends on livestock for the pricing mechanism to be effective.				
				The response to the pricing of GHG emissions also negatively impacts production from livestock.	I: milk/meat: –	I: milk/meat: –	I: milk/meat: –	I: milk/meat: – –
	Fibre	e.g. timber, wools	Yes	Pricing biological GHG emissions is predicated on biological emissions so depends on livestock for the pricing mechanism to be effective.				
				The response to the pricing of emissions also negatively impacts fibre production from livestock (i.e. wool) but positively impacts timber production.	I: timber: + I: wool: –	I: timber: + I: wool: –	I: timber: + I: wool: –	I: timber: ++ I: wool: – –
	Freshwater	e.g. irrigation, stock watering, electricity generation, transport industrial/ commercial water, drinking water	Potentially	There is potentially a dependency on freshwater if any of the mitigation options resulted in a change in irrigation use or stock water usage.				
				In the mitigation options used in this analysis there was no change in irrigation use in any of the mitigation options.	D: irrigation: NC	D: Irrigation: NC	D: Irrigation: NC	D: Irrigation: NC
				The reduction in dairy and sheep & beef stock numbers at higher GHG prices means there will be decreases in reliance on stock water. However, this is expected to be small.	D: Stock water: NC	D: Stock water: NC	D: Stock water: –	D: Stock water: –
				Increase in forestry on farms could potentially decrease water yield, which could potentially lead to a decrease in freshwater availability for consumptive uses.	I: Water availability: –	I: Water availability: –	I: Water availability: –	I: Water availability: –
	Wildfoods	e.g. food gathering/ mahinga kai	Potentially	There are potential indirect impacts on freshwater wildfoods. Pricing GHG emissions has positive impacts on nutrient losses, which in turn could also have positive effects on aquatic wildfoods. There may also be positive impacts on terrestrial wildfoods from forested areas.	I: ?+	I: ?+	I: ?+	I: ?+

ES cat.	Ecosystem service	Ecosystem service descriptors	Relevance	Impact and/or dependency	Expected effects of a GHG price GHG1	GHG2	GHG3	GHG4
	Ornamental resources	e.g. flax	Unlikely					
	Fuel	e.g. forest biomass	Potentially	There are potential positive impacts on biomass fuels. The impact will depend on whether the additional forest resources are used for biomass fuel and/or timber.	I: ?+	I: ?+	I: ?+	I: ?+
	Biochemical & natural medicines		Uncertain	The effect on biochemical and natural medicines is uncertain.				
	Genetic resources		Unlikely	The effect on genetic resources is uncertain.				
Regulating (benefits from regulation of ecosystem processes)	Water purification	e.g. cleaning, dilution and disposal of waste nutrient assimilation	Yes	The response to the pricing of GHG emissions has positive impacts on nutrient leaching.	I: Nutrients: +	I: Nutrients: +	I: Nutrients: +	I: Nutrients: ++
				The decrease in stock numbers at higher GHG prices is also likely to lead to some decrease in *E.coli* leaching. The magnitude of that decrease will depend on a number of factors, including whether there are less stock in waterways or close to waterways.	I: *E.coli*: ?+	I: *E.coli*: ?+	I: *E.coli*: ?+	I: *E.coli*: ?++
	Water regulation	e.g. flood control	Yes	With the uptake of the planted forestry mitigation option on sheep & beef/dairy land in response to the pricing of GHG emissions, there is likely to be an improvement in the water regulation service, particularly flooding.	I: high flows: +	I: high flows: +	I: high flows: +	I: high flows: +
	Climate regulation	e.g. riparian & aquatic vegetation sequestering carbon	Yes	The reduction in GHG emissions in response to pricing GHG emissions has positive impacts on global climate regulation (see Table 8).	I: +	I: +	I: +	I: ++
	Air quality maintenance	e.g. sink for industrial emissions	Potentially	With the increase in planted forestry on sheep & beef / dairy land, there is potential for a negative impact on air quality; particularly from pine pollen (should pine be the forest species).	I: pollen: ?-	I: pollen: ?-	I: pollen: ?-	I: pollen: ?-
	Erosion control	reducing sediment	Yes	With the uptake of the planted forestry mitigation option on sheep & beef / dairy land in response to the pricing	I: +	I: +	I: +	I: ++

ES cat.	Ecosystem service	Ecosystem service descriptors	Relevance	Impact and/or dependency	Expected effects of a GHG price			
					GHG1	GHG2	GHG3	GHG4
				of GHG emissions, there is likely to be an improvement in the erosion control service.				
	Natural hazard protection	e.g. floods, storms, droughts	Yes	Related to the water regulation service, there are likely to be improvements in flood control from the increased uptake of forestry.	I: flooding: +	I: flooding: +	I: flooding: +	I: flooding: +
	Biological control	e.g. insect control of weeds	Uncertain	The effect on biological control is uncertain.				
	Human disease regulation		Unlikely	The effect on human disease regulation is unlikely.				
	Pollination		Uncertain	The effect on biological control is uncertain.				
Cultural (non-material benefits obtained from ecosystems)	Recreation & ecotourism	e.g. swimming, boating, fishing, etc. Hiking Mountain biking	Potentially	The impact on recreation and ecotourism is uncertain. However, the decrease in livestock numbers at higher GHG prices has the potential to decrease *E.coli* in waterways, which has positive impacts on primary and secondary contact in freshwater. Depending on where the new forests are located, there could be shading and habitat benefits for aquatic species. This in turn has the potential to improve the recreational fishery.	I: Water activities: ?+	I: Water activities: ?+	I: Water activities: ?+	I: Water activities: ?+
				Given the dispersed nature of new forests, there are unlikely to be any significant new recreational uses.	I: Land activities: ?NC	I: Land activities: ?NC	I: Land activities: ?NC	I: Land activities: ?NC
	Ethical & spiritual values	e.g. aesthetic values (e.g. views) Spiritual & religious values Cultural heritage values Social relations Sense of place Cultural diversity	Potentially	Depending on the location of the additional forest areas the landscape views will change. Whether these changes are viewed as positive or negative is uncertain. Other mitigation options are unlikely to affect aesthetic values.	I: Views: ?+/–	I: Views: ?+/–	I: Views: ?+/–	I: Views: ?+/–
				Similar to landscape views, sense of place may change depending on the extent and location of additional forested area across the landscape. Whether these changes are viewed as positive or negative is also uncertain. The mitigation options analysed are unlikely to depend on or affect the other types of ethical and spiritual	I: Sense of place: ?+/–	I: Sense of place: ?+/–	I: Sense of place: ?+/–	I: Sense of place: ?+/–

ES cat.	Ecosystem service	Ecosystem service descriptors	Relevance	Impact and/or dependency	Expected effects of a GHG price GHG1	GHG2	GHG3	GHG4
				values.				
	Inspirational & educational values	Inspiration Knowledge systems	Unlikely	The mitigation options analysed are unlikely to depend on or affect the inspirational and educational values.				
Supporting (services necessary for the production of all other services)	Provisioning of habitat	e.g. ecosystem health and general protection for indigenous species (e.g. birds, fish) fish spawning (e.g. trout or inanga)	Potentially	Freshwater habitat may improve with additional forested areas on farms and reduced stocking rates. This, in effect, is indirect as the improvement in habitat will come through improved water purification, erosion control, and water regulation services.	I: freshwater: ?+	I: freshwater: ?+	I: freshwater: ?+	I: freshwater: ?+
				Terrestrial habitats will also be affected by the additional forested area. The location of these forested areas in the landscape could influence habitat connectivity (potentially positive in terms of new habitat and negative in terms of pest pathways).	I: terrestrial: ?+/–	I: terrestrial: ?+/–	I: terrestrial: ?+/–	I: terrestrial: ?+/–
				It is uncertain how the soil microbial habitats will be affected by the mitigation options. However, mitigation options that involve reducing fertiliser use are likely to have some impact on microbial habitat.	I: soil: ?	I: soil: ?	I: soil: ?	I: soil: ?
	Nutrient & water cycling	Nutrient cycling	Potentially	The reduction in fertiliser use may potentially alter nutrient cycling. Additional forested areas may affect water cycling. The effects, however, are uncertain.	I: water/nutrient cycling: ?	I: water/nutrient cycling: ?	I: water/nutrient cycling: ?	I: water/nutrient cycling: ?
	Primary production	Not relevant						
	Production of atmospheric oxygen	Not relevant						
	Soil formation & retention	Not relevant						

D: dependency; I: impact; + improve; – decline; ? unsure; NC no change; multiple '+' or '–' indicates greater impact or dependency;

?– or ?+: unsure if there is an impact/dependency but if there is it negative (–) or positive (+).

7 Conclusions

This report assessed the economic and environmental impacts of adopting mitigation options under four different GHG price scenarios for biological GHG emissions from agriculture. These impacts were projected to 2030 and 2050 at regional and national levels for the agricultural sector (using the NZFARM model) and the wider economy (using the ESSAM model).

Given the focus of the analysis was to better understand the uptake of mitigation options in response to GHG prices and the corresponding economic implications, this analysis did not consider land-use change (except partial planting of forestry), the adoption of innovative technologies to increase agricultural productivity (except for one mitigation option in one of the analyses), or the abandonment of farming activity. We also reviewed the potential barriers to the adoption of mitigation options and provided a qualitative assessment of the broader costs and benefits, using an ecosystem services framework, of pricing biological GHG emissions.

Based on discussions with experts from DairyNZ, we identified seven dairy mitigation options that reduce GHG emissions to consider in our analysis. Similar discussions with experts from Beef + Lamb New Zealand identified three mitigation options for the sheep & beef sector. Through discussions with industry representatives it was apparent that the uptake of mitigation options by farmers depends on the individual circumstances of farmers. This was particularly so for the sheep & beef sector, where there is significant heterogeneity in land characteristics as well as farmers' behaviours.

The key barriers identified internationally and confirmed by sector experts for the adoption of mitigation options are related to the actual or perceived effects of a mitigation option on farm performance and profitability. Through the NZFARM analysis we are able to account for this concern as the model maximises sector profitablity subject to contraints or signals such as the pricing of GHG emissions. Our analysis showed that the agricultural sectors adopted the most profitable and the most GHG-reducing mitigation options. The rate of adoption and the mitigation options adopted varied across farm systems/types in the dairy and sheep & beef sectors, and across regions.

As expected, higher GHG prices lead to the greater adoption of mitigation options. GHG prices reduce profits and incentivise the adoption of mitigation options that reduce GHG emissions. The emission abatement was often not proportional to the decrease in profits. An increase in GHG prices may increase the cost of farming, which reduces profits but only results in a small decrease in GHG emissions. This means that for some farming systems/types in some regions there may not be a mitigation option that is able to mitigate the negative effects of GHG prices on profits. At the highest GHG price in 2050, the sheep & beef sector in aggregate experiences financial losses.

While land-use change (outside a partial conversion to farm forestry) is not included in our analysis, farms that are unprofitable over the long term may change their land use and enterprise structure (e.g. from dairy farming to horticultural farming) or exit the industry. Our analysis does not account for this change, but is able to isolate the effects of pricing biological GHG emissions given the suite of mitigation options currently available (Analysis I), and with an additional mitigation option that not only reduces GHG emissions but also increases productivity in the dairy sector (Analysis II).

Our analysis shows marked decreases in profits when the available mitigation options do not increase the profitability of the livestock sectors. We could expect that farmers within the dairy and sheep & beef sectors would be incentivised to change land use rather than adopt mitigation options that do not increase their financial viability. Therefore, given that skills are a key reason for adopting mitigation options, then upskilling the agricultural sector to assist with the transition to other agricultural industries or sectors is likely to be an important part of implementing the pricing of biological GHG emissions.

For the sheep & beef sector, most of the reduction in GHG emissions is achieved at the lowest GHG price. This is similar for the dairy sector when there are mitigation options that increase dairy productivity. However, when there are no productivity increasing mitigation options, higher GHG prices are needed to achieve greater reductions in GHG emissions, and this comes at a larger cost to the dairy sector.

There are also co-benefits associated with the adoption of mitigation options. We noted several benefits in the qualitative assessment of ecosystem services related to the reduction in the intensity of farming operations and the uptake of farm forestry.

It is important also to consider the scale of the analysis. At the whole economy scale the effect of pricing biological GHG emissions on the entire economy is negligible, even under the highest GHG prices. This is because the slight lift in the terms of trade is enough to prevent a reduction in New Zealand's real gross national disposable income and private consumption. Employment effects are negative in aggregate, but not large, with the reduction of employment in pasture and other farming activities being offset by employment gains in forestry and a marginal increase in labour intensity.

8 Acknowledgements

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9 References

Brown P 2015. Survey of Rural Decision Makers. Landcare Research NZ Ltd. www.landcareresearch.co.nz/srdm2015 (accessed 7 June 2018). DOI: 10.7931/J28913S8

Daigneault A, Greenhalgh S, Samarasinghe O, Jhunjhnuwala K, Walcroft J, Montes de Oca Munguia O 2012. Sustainable land management and climate change – catchment analysis of climate change. SLMACC final report.

Daigneault AJ, Greenhalgh S, Samarasinghe O 2017. Economic impacts of multiple agro-environmental policies on New Zealand land use. Environmental and Resource Economics. https://doi.org/10.1007/s10640-016-0103-6

DairyNZ Economic Group 2017. Mitigation options to reduce GHG emissions on New Zealand dairy farms: GHG mitigation modelling – dairy project. Prepared for the Biological Emissions Reference Group (BERG).

DairyNZ Economic Group 2018. A comparison of stocking rate approaches to reduce GHG emissions: on-farm mitigation options to reduce GHG emissions on New Zealand dairy farms. Prepared for the Biological Emissions Reference Group (BERG).

Dorner Z, Djanibekov U, Soliman T, Stroombergen A, Kerr S, Fleming D, Cortes-Acosta S, Greenhalgh S 2018. Land use change as a mitigation for climate change: Report 1, LURNZ and NZFARM model runs results. Report to the Biological Emissions Reference Group (Project No. 18398). Motu Economic and Public Policy Research.

GRA (Global Research Alliance on Agricultural Greenhouse Gases) and Sustainable Agricultural Initiative (SAI) Platform from LRG (Livestock Research Group) 2015. Reducing greenhouse gas emissions from livestock: best practice and emerging options. Available from: http://www.ccacoalition.org/en/resources/reducing-greenhouse-gas-emissions-livestock-best-practice-and-emerging-options (accessed April 2017).

Ministry for the Environment (MFE) 2017. New Zealand's greenhouse gas inventory 1990–2015. Wellington, New Zealand, 502pp.

Motu 2017. Barriers to adoption of no-cost options for mitigation of agricultural emissions: a typology. Available from: https://motu.nz/our-work/environment-and-resources/agricultural-economics/no-cost-barriers/barriers-to-adoption-of-no-cost-options-for-mitigation-of-agricultural-emissions-a-typology/ (accessed April 2017).

Ranganathan J, Raudsepp-Hearne C, Lucas N, Irwin F, Zurek M, Bennett K, Ash N, West P. 2008. Ecosystem services: a guide for decision makers. Washington (DC): World Resources Institute.

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. Wellington, Ministry for Primary Industries.

Reisinger A, Clark H, Journeaux P, Clark D, Lambert G 2017. On-farm options to reduce agricultural GHG emissions in New Zealand. Report to the Biological Emissions Reference Group. New Zealand Agricultural Greenhouse Gas Research Centre.

Shepherd M, Daigneault A, Clothier B, Devantier B, Elliott S, Greenhalgh S, et al. 2016. New Zealand’s freshwater reforms: what are the potential impacts on greenhouse gas emissions? A synthesis of results from two independent studies. MPI Technical Paper 2017/21. Wellington, Ministry for Primary Industries.

Stroombergen A 2010. The international effects of climate change on agricultural commodity prices, and wider effects on New Zealand. Motu working paper 10-14.

Stroombergen A 2011. The economic implications of climate-induced changes in agricultural production. Report for NIWA. Wellington, Infometrics.

Stroombergen A 2012. Long term investment under uncertain carbon prices. Report for Motu. Wellington, Infometrics.

Stroombergen A 2015. A general equilibrium analysis of options for New Zealand's post-2020 climate change contribution. Wellington, Ministry for the Environment. http://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/general-equilibrium-analysis_0.pdf

World Resources Institute. 2012. The corporate ecosystem services review: guidelines for identifying business risks and opportunities arising from ecosystem change. Washington (DC): World Resources Institute. Version 2.0.

Wreford A, Ignaciuk A, Gruère G 2017. Overcoming barriers to the adoption of climate-friendly practices in agriculture. OECD Food, Agriculture and Fisheries Papers, No. 101. Paris, OECD. DOI: 10.1787/97767d8-en

Appendix 1 – NZFARM model description

NZFARM is a comparative-static and mathematical programming model of New Zealand land use developed by MWLR (Daigneault et al. 2012, 2017). The model provides decision-makers with information on the economic *ex ante* impacts of possible new environmental policies and technologies, as well as how a new policy aimed at one environmental issue could affect other environmental factors and agricultural and forestry production. The model can assess changes in technology, land-use commodity supply, resource constraints, and effects of farm, resource and environmental policies on economic and environmental indicators important for farmers and policy-makers. NZFARM tracks environmental variables such as GHG emissions from agricultural land uses. The NZFARM model can be modified and adjusted depending on study conditions.

The model's objective function is to determine the level of agricultural production that maximises the summed profits from all regions of New Zealand, subject to land area (that is fixed and does not change between farm enterprises) and management/mitigation options, agricultural production costs, and output prices. Hence, the objective function of the model maximises the profits from land uses for all New Zealand. We assume in the model the earnings before tax and interest from land uses.

To enable the agricultural sector to respond to policy changes and resource constraints, dairy and sheep & beef farmers can adopt management practices with lower environmental (particularly GHG) impacts. We assume the constraint restricting the land-use change, where only adoption of mitigation options at dairy and sheep & beef farms is included. Hence, other land uses are considered to be constant and do not change with respect to GHG prices in the model. A schematic representation of NZFARM model used for this study is given in Figure 2.

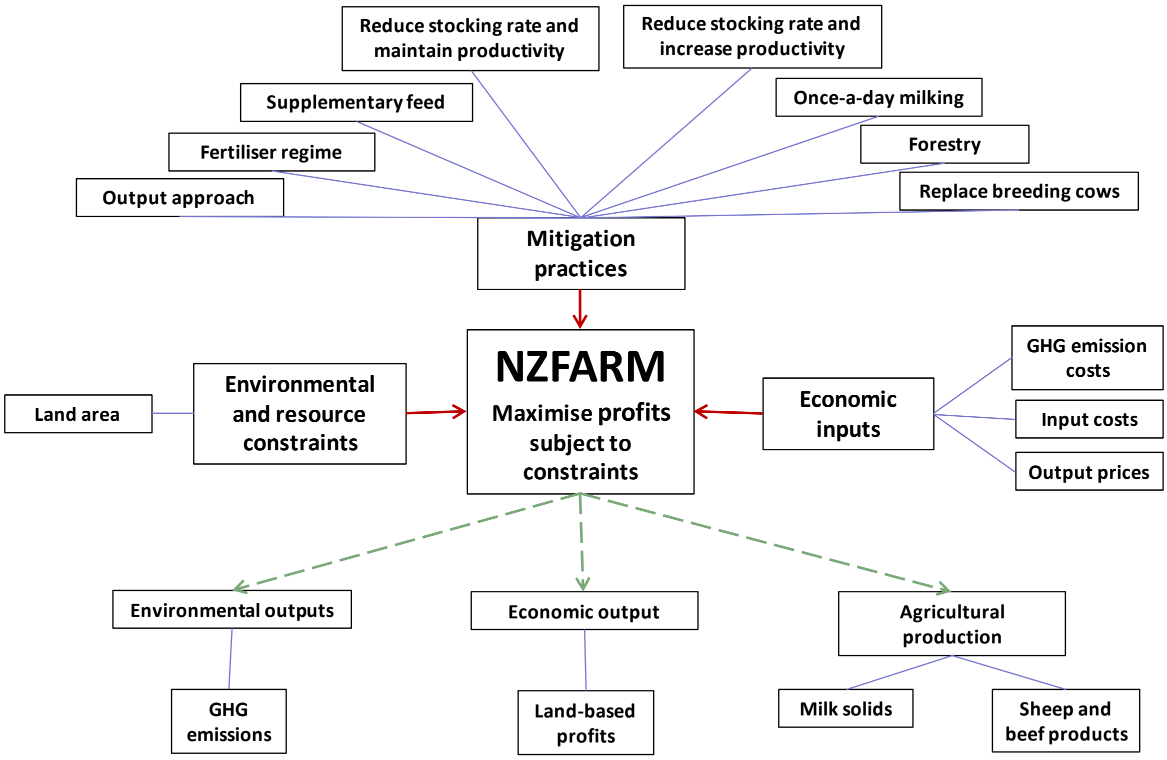

Figure 2: Schematic view of the NZFARM model (adapted from Diagnault et al. 2017).

In more detail, the mathematical representation of the objective function is as follows:

$$Max\ NR = \sum_{r,l,e,m} \{PQ_{r,l,e,m} - X_{r,l,e,m}\left[\omega^{live}_{r,l,e,m} + \omega^{vc}_{r,l,e,m} + \omega^{fc}_{r,l,e,m}\right] + \tau\ env_{r,l,e,m,seq}X_{r,l,e,m} - \varphi\ env_{r,l,e,m,ghg}X_{r,l,e,m}\} \qquad (1)$$

where:

NR is the maximum level of profits for New Zealand

P is the product output price

Q is the product output

Y is other gross income earned by farmers

X is the farm-based activity

ω^{live}, ω^{vc}, ω^{fc} are the respective livestock, variable, and fixed input costs

τ is a payment for C sequestration in forestry activities

seq is a C sequestration level coefficient in forestry

φ is a price imposed on landowners for GHG emissions from agricultural land uses (in \$/tCO_2-e)

ghg is a GHG emission levels from agricultural land uses.

The total profit for New Zealand includes the profits across all regional zones of New Zealand (*r*); land uses (*l*) such as pasture, forestry, arable, horticulture; farm enterprises (*e*) such as dairy, sheep & beef, deer, other pasture, vegetables, fruits, pipfruit, viticulture, arable, and forestry; and on-farm management practices (m) of dairy and sheep & beef farms. The productivity of land uses and their output and input prices remain constant throughout the analysed periods due to insufficient information to make projections for profits and commodity output levels of all simulated land uses. We assume that the GHG prices for emissions adjust with the interest rate over years. Also, we assume that the payment level for C sequestration in forestry changes over the years according to the interest rate.

The maximisation of profit is affected by the output and input prices, agricultural production amount, land area, and land-use area constraints. For instance, production is constrained by the product balance equation that specifies production type by an activity type in different regions. The production constraint is specified as follows:

$$Q_{r,l,e,m} \leq \alpha_{r,l,e,m}^{proc} X_{r,l,e,m} \tag{2}$$

where $\alpha_{r,l,e,m}^{proc}$ is the output coefficient from land uses that shows the output levels from land-use activity in each region.

The choice variable in the model is an allocation area for different mitigation options. Land uses in 16 administrative regions that are given in the NZFARM are constrained by the available land area, such as:

$$\sum_{m} X_{r,l,e,m} = L_{r,l,e} \tag{3}$$

where L is the available land type area such as pasture, forestry, arable, horticulture, conservation area and other land in each region of New Zealand. In equation 3 we assume that there is a fixed area of farm enterprises and only the area of mitigation options can change. We also assume in the model the land-use change in the form of forestry for dairy and sheep & beef farms and consider it as a mitigation option.

The model can also include a constraint on changes for enterprise areas:

$$X_{r,l,e,m} = X_{r,l,e,m}^{init} \tag{4}$$

where $X_{r,l,e,m}^{init}$ is the area of land uses initially included in the model.

The NZFARM model also calculates the change in environmental outputs when the land-users maximise profits. We consider GHG emissions as environmental outputs resulting from land uses. The equation for environmental outputs is included into the model as follows:

$$env_{r,l,e,o,m}X_{r,l,e,m} = EN_{r,l,e,o,m} \tag{5}$$

where env is the coefficient of environmental indicators such as GHG emissions from land uses, EN is the variable of environmental outputs from selected land uses by the model, and o is the set that consists of environmental indicators.

The model variables are subject to non-negativity constraint, where variable areas are constrained to be greater or equal to zero such that farmers cannot feasibly have negative area of land and agricultural outputs:

$$Q, X, L \geq 0 \tag{6}$$

In the model, the main endogenous (i.e. choice) variable is the land-use area for dairy and sheep & beef farms under different management practices ($X_{r,l,e,m}$). NZFARM considers that farmers have a degree of flexibility to adjust the share of the land use and enterprise their farm-based activities to meet an objective target such as maximum profits. Commodity prices and environmental constraints are exogenous variables, except GHG emission and C sequestration prices, and these variables are assumed to be constant across scenarios.

The model is programmed in the General Algebraic Modelling System (GAMS).[18]

[18] https://www.gams.com/

Appendix 2 – ESSAM model description

The ESSAM model is a computable general equilibrium (CGE) model of economic activity, energy, and GHG emissions (including biological emissions) that considers the whole economy of New Zealand (Stroombergen 2015). The model evaluates how introduced changes in economic activity, such as GHG emission prices, can reverberate across the entire economy of New Zealand.

To estimate the economy-wide impacts on GDP and other key national indicators, changes in farm production simulated by NZFARM were up-scaled to the national level using the ESSAM model. In particular, NZFARM simulates changes in detail for each land use / farm system considering various biophysical and environmental conditions. These NZFARM simulation results are then incorporated by the ESSAM model to provide analysis at a more aggregated scale to indicate changes to the New Zealand economy.

This will help illustrate how sensitive the national economic activity is to the estimated changes in farming systems in response to GHG pricing scenarios. We do not consider the land-use change in the model, except conversion of dairy and sheep & beef farm area into forestry. Also, by using ESSAM, we are interested in understanding the economy-wide effects of the on-farm mitigation options.

The following model closure rules are adopted for the alternative scenarios, consistent with generally accepted modelling practice.[19, 20]

1 The current account balance is fixed as a percentage of GDP. This means, for example, that if New Zealand needs to purchase international emissions units to meet an emissions responsibility target, that liability cannot be met simply by borrowing more from offshore with unknown or indefinitely deferred repayment.
2 The post-tax rate of return on investment is unchanged between scenarios. This acknowledges that New Zealand is part of the international capital market and ensures consistency with the preceding closure rule.
3 Any change in the demand for labour is reflected in changes in wage rates, not changes in employment. Instead of fixed employment, wage rates could be fixed at reference scenario levels. This would imply, however, that the long-run level of total employment is driven more by emissions policy in agriculture than by the forces of labour supply and demand, which we consider unlikely.

The fiscal balance is fixed across scenarios. This means, for example, that if the government needs to purchase overseas emission units, it must ensure that it has matching income. If it earns insufficient income from the sale of domestic emission units (because of free allocation, for example) it would have to adjust tax rates. We assume that

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[19] NZIER and Infometrics 2009. Economic modelling of New Zealand climate change policy. Report to Ministry for the Environment.

[20] NZIER and Infometrics 2009. Macroeconomic impacts of climate change policy. Impact of Assigned Amount Units and International Trading. Report to Ministry for the Environment, 20pp.

net personal income tax rates are the default equilibrating mechanism, although changing government expenditure is an alternative option that could be used.

Appendix 3 – Mitigation options to reduce agricultural GHG emissions

A commentary on mitigation options to reduce agricultural GHG emissions

A 2015 joint publication by the Global Research Alliance on Agricultural GHG and the Sustainable Agriculture Initiative documents a range of low- and no-cost opportunities to reduce GHGs in the animal production systems (GRA 2015). The authors report that reducing emission intensity on-farm will not necessarily lead to lower absolute emissions, which depend on total production and the responses of farmers to wider market and policy signals. However, as food demand is largely out of the control of individual farmers, a focus on emissions intensity on-farm presents a realistic approach to reduce supply-side emissions without precluding other actions to manage the demand for livestock products (GRA 2015).

Several key opportunities for immediate action are summarised: improving feed quality and digestibility; improving animal health and husbandry; manure management: collection, storage and utilisation; and precision livestock farming.

Improving feed digestibility and energy content and better matching protein supply to animal requirements can improve nutrient uptake, increase animal productivity and fertility, and thus lower emissions per unit of product (GRA 2015). However, care needs to be taken that emissions from off-farm production of supplementary feeds and/or processing do not outweigh any on-farm reductions.

Improved animal health and husbandry through farmer education and the availability of animal health diagnostic tools and therapeutics can increase productivity, reduce mortality rates, and reduce the age of first reproduction and replacement rates. Improved animal health would generally reduce emissions intensity, as healthier animals are more productive, and thus produce lower emissions per unit of output.

Efficient manure collection and storage can reduce manure emissions and improve animal productivity.

Precision livestock farming caters for the individual animal's needs in bigger herds. This practice can be enabled by sensor technology integrated in monitoring systems. Precision application of fertiliser and irrigation, aided by remote sensing of soil moisture, pasture growth and quality, can improve resource efficiency use and reduce GHG emissions. Furthermore, for some farms, reducing overstocking can deliver higher-quality and quantity of feed and health care and thus increase productivity of individual animals, which can in turn maintain overall farm profitability while reducing absolute emissions and emission intensity.

We did not include in the analysis other options such as nitrification inhibitor DCD as a mitigation due to its minor GHG emission reductions and (importantly) the fact that it is not available in the market as a result of leaving residues in dairy products (Reisinger & Clark 2016). Other mitigation options such as manure management and selective breeding were also not considered in this study. Other practices and technologies such as housing/stand-off pads and urease inhibitor have a limited GHG mitigation potential (Reisinger et al. 2017).

We did not consider the above different mitigations, but included the mitigation options for dairy (options 1–7) and sheep & beef (options 1–3) farms detailed below. Mitigation options were selected based on discussion with BERG experts and other experts from industries during the workshops and subsequent interviews.

It should be noted that we are considering long-term analysis till the year 2050. During this period of time there might be technological advancements that will increase agricultural productivity and reduce costs and GHG emissions. In addition, in such a long-term period there are often uncertainties related to climate, markets and policy changes as well as other factors (e.g. increase in floods, pest attacks, fluctuations in interest rate) that will affect the agricultural productivity, profits and GHG emissions. These technological advancements and uncertainties need to be considered in future analyses.

Dairy sector mitigation options

Mitigation options for the dairy sector are either output or input related, as outlined in the six mitigation options below.

Output oriented

- Option 1: The output approach is a mixed adjustment (it considers combinations of different mitigation options given below) and will be different for each farm. This is the mitigation approach that DairyNZ usually uses for water related issues. For example, this mitigation option includes scenarios with a GHG reduction target of 5%, 10%, 15% and 20% from baseline/current situation;

Input oriented

The next five mitigation options (Options 2–6) relate to the input use approach.

- Option 2: reduce nitrogen (N) fertiliser (e.g. reduce by 25%, 50%, 75%, and, no N fertiliser use)
- Option 3: change in supplementary feed, reduce supplementary feed and/or switch some supplementary feed to low protein options
- Option 4: reduce stocking rate and maintain milk solid production per cow
- Option 5: apply once-a-day milking (e.g. once-a-day milking for half a season, for entire season)
- Option 6: plant forestry/tree plantations on the milking platform; the remaining dairy farm is smaller, but stocking rates and production per hectare remain unchanged
- Option 7: reduce stocking rate and increase milk solid production per cow.

Five dairy systems are modelled that correspond to the New Zealand dairy systems with differing management practices. DairyNZ used 27 farms in their modelling sample, spread over five farm systems:

- systems 1–2 (low intensity)
- system 3 (medium)
- system 4–5 (high intensity).

Sheep & beef sector mitigation options

For the sheep & beef sector, information was obtained from Beef + Lamb New Zealand. According to the Beef + Lamb New Zealand farm survey, there are six types of sheep & beef farms, classified based on topology and intensification/management practice:

- hard hill sheep & beef farms
- high country sheep & beef farms
- hill country sheep & beef
- finishing breeding sheep & beef
- intensive finishing sheep & beef
- mixed finishing sheep & beef.

Six mitigation options were identified for sheep & beef farms (Reisinger et al. 2017):

- Option 1: reduction in stocking rates / maintain or increase productivity (i.e. output of sheep and beef products)
- Option 2: removal of breeding cows
- Option 3: land-use change that includes planting trees instead of land allocation for sheep and beef
- Option 4: alter sheep to cattle ratio
- Option 5: removal of N fertiliser use
- Option 6: increase male / decrease female cattle.

Of these, options 1, 2 and 3 were included in the NZFARM modelling.

Appendix 4 – Data on mitigation options

Table 33 and Table 34 provide information obtained from DairyNZ on GHG emissions and profits for five dairy farm systems. Dairy data differ for no mitigation and mitigations by dairy systems and across regions. Hence, tables present the summary statistics and show mean, standard deviation, 90th, 70th, 30th, and 10th percentiles that include different dairy systems across regions. The tables show the absolute values for no mitigation options and relative (%) change of mitigation options from no mitigation. For more information on dairy mitigation options, see DairyNZ Economic Group (2017, 2018).

Table 33. Summary statistics of relative change (%) in greenhouse gas emissions for dairy farms under different mitigation options, per hectare

Mitigation option	Mean	Std dev.	90th percentile	70th percentile	30th percentile	10th percentile
No mitigation, kg CO_2/ha	**9,220**	**1,666**	**11,519**	**10,238**	**8,122**	**7,325**
Output approach reducing GHG emissions, % change from no mitigation						
5% reduction	–3.9	–4.8	–4.5	–3.1	–4.4	–3.4
10% reduction	–7.6	–7.9	–8.4	–6.2	–8.3	–7.1
15% reduction	–11.8	–10.3	–12.7	–10.9	–13.3	–12.6
20% reduction	–15.5	–15.4	–17.4	–16.1	–15.9	–16.7
Reduction in fertiliser use, % change from no mitigation						
25%	–4.4	–6.2	–5.3	–7.1	–5.3	–4.1
50%	-8.8	–11.6	–10.4	–12.5	–10.2	–8.9
75%	–13.2	–17.0	–13.2	–16.9	–14.2	–14.0
No fertiliser use	–17.6	–21.5	–16.0	–22.3	–17.4	–18.9
Change in supplementary feed, % change from no mitigation						
Switch 50% of supplementary feed to low protein feed	–0.2	–1.2	–0.1	–0.3	–0.2	0
Switch 100% to low protein feed	–0.5	–2.2	–0.3	–0.2	–0.5	–0.2
Reduce imported high protein volumes by 50% and reduce stocking rate	–2.3	–2.8	–3.4	–5.9	–2.0	–2.1
Remove all imported high protein volumes and reduce stocking rate	–5.1	–5.5	–6.7	–9.4	–3.9	–4.0
Reduction in cow numbers and same milk production per cow, % change from no mitigation						
5%	–5.4	-6.3	–5.9	–6.5	–5.6	–6.5
10%	–11.0	–13.6	–12.1	–14.0	–11.6	–14.1
15%	–16.3	–17.8	–17.8	–18.2	–17.7	–19.3
20%	–21.0	-23.2	–22.7	–23.0	–22.2	–23.4
Once-a-day milking, % change from no mitigation						
Half a season	–0.7	0.9	–0.9	0	–0.5	–2.2
Entire season	–1.1	1.6	–1.8	–0.6	–0.8	–3.1

Mitigation option	**Mean**	**Std dev.**	**90th percentile**	**70th percentile**	**30th percentile**	**10th percentile**
No mitigation, kg CO_2/ha	**9,220**	**1,666**	**11,519**	**10,238**	**8,122**	**7,325**
Planting forestry on milking platform, % change from no mitigation						
5% forestry	–3.5	2.7	–3.7	–4.6	–6.1	–4.7
10% forestry	–7.1	7.1	–7.1	–7.3	–10.3	–11.3
15% forestry	–10.3	11.1	–9.1	–11.0	–14.1	–16.3
20% forestry	–13.3	15.7	–9.6	–14.9	–17.7	–21.0
Reduction in cow numbers and increase in milk production per cow, % change from no mitigation						
5%	–4.7	–5.0	–4.7	–5.7	–5.3	–5.5
10%	–10.3	–11.5	–10.6	–13.1	–10.6	–12.8
15%	–15.5	–14.9	–15.2	–17.3	–16.9	–19.0
20%	–20.0	–20.2	–20.7	–22.4	–20.7	–22.8

Source: DairyNZ Economic Group (2017).

Table 34. Summary statistics of relative change (%) in profits of dairy farm under different mitigation options, per hectare

Mitigation option	Mean	Std dev.	90th percentile	70th percentile	30th percentile	10th percentile
No mitigation, $/ha	**1,599**	**768**	**2,515**	**1,915**	**1,216**	**688**
Output approach reducing GHG emissions, % change from no mitigation						
5% reduction	–2.4	–2.5	–2.0	–2.3	–8.1	–2.4
10% reduction	–6.5	–4.2	–5.3	–5.4	–16.8	–7.2
15% reduction	–11.3	–7.1	–9.4	–9.2	–23.3	–14.2
20% reduction	–15.9	–8.9	–13.9	–10.2	–29.4	–21.8
Reduction in fertiliser use, % change from no mitigation						
25% reduction	–4.5	–1.1	–3.6	–1.8	–8.5	–8.1
50% reduction	–9.0	–2.6	–7.5	–3.7	–17.4	–17.2
75% reduction	–13.3	–4.1	–12.5	–6.4	–23.7	–25.9
No fertiliser use	–18.2	–5.4	–17.2	–9.4	–29.7	–34.0
Change in supplementary feed, % change from no mitigation						
Switch 50% of supplementary feed to low protein feed	–1.9	–1.8	–3.0	–0.2	–2.6	–1.6
Switch 100% to low protein feed	–4.0	–3.1	–5.1	–0.8	–7.3	–5.8
Reduce imported high protein volumes by 50% and reduce stocking rate	–2.6	–0.9	–2.0	–5.0	–3.2	–1.3
Remove all imported high protein volumes and reduce stocking rate	–5.8	–4.0	–4.6	–8.0	–8.3	–2.3
Reduction in cow numbers and same milk production per cow, % change from no mitigation						
5% reduction	–6.2	–2.6	–2.8	–5.4	–10.4	–10.8
10% reduction	–12.3	–5.9	–8.4	–9.4	–19.5	–23.1
15% reduction	–18.4	–10.0	–13.7	–12.9	–28.4	–34.5
20% reduction	–25.1	–13.2	–20.1	–17.9	–35.4	–47.5
Once-a-day milking, % change from no mitigation						
Half a season	–3.6	0.2	0.0	–0.2	–11.9	–5.9
Entire season	–2.1	0.2	0.0	–0.2	–7.3	–0.2
Planting forestry on milking platform, % change from no mitigation						
5% forestry	–7.8	–3.6	–5.6	–7.2	–16.6	–17.5
10% forestry	–16.4	–6.4	–13.3	–14.9	–31.7	–34.7
15% forestry	–25.1	-7.4	–18.8	–22.3	–38.3	–49.2
20% forestry	–31.8	–8.3	–21.6	–28.3	–52.2	–65.7
Reduction in cow numbers and increase in milk production per cow, % change from no mitigation						
5%	0.1	-0.3	0.0	0.0	0.0	2.2
10%	0.1	-0.4	0.0	0.0	0.0	3.5
15%	0.2	-0.6	0.0	0.0	0.0	5.3
20%	0.4	-0.9	0.0	0.0	0.0	8.1

Source: DairyNZ Economic Group (2017).

Table 35 shows the mean profit and GHG emission values for sheep & beef classified by land-use topology and management practice. Values for no mitigation are in absolute terms, while relative change (%) values are shown for mitigation options. Data on profit stocking rate (sheep, beef cattle, deer and goats) and production (wool, lamb, beef and venison) from different sheep & beef systems were obtained from the sheep & beef farm survey of Beef + Lamb New Zealand. Based on this survey, we considered six systems/types for sheep & beef farms. The relative effect of sheep & beef farm mitigation options was obtained from Reisinger et al. 2017.

Table 35. Relative change (%) in profits and greenhouse gas emissions of sheep & beef farm under different mitigation options, per hectare

Mitigation option	Farm system	Impact	
		Profit (%)	GHG emission (%)
No mitigation*	NI hill	310 $/ha	3.49 t/ha
	NI intensive	402 $/ha	4.11 t/ha
	SI hill	90 $/ha	0.92 t/ha
	SI intensive	549 $/ha	3.59 t/ha
Reduction in stocking rates and maintain production, % change from no mitigation			
	NI intensive	–10%	–4%
	NI hill	–4%	–5%
	SI intensive	–26%	–7%
	SI hill	–15%	–10%
Removal of breeding cows, % change from no mitigation			
	NI hill	62%	–4%
	S hill	165%	–1%
Planting forestry, % change from no mitigation			
10%	NI hill	–11%	–25%
	SI hill	–11%	–14%
20%	NI hill	–23%	–48%
	SI hill	–21%	–24%
30% forestry	NI hill	–35%	–71%
	SI hill	–30%	–35%
10% forestry and lower total production	NI hill	–16%	–27%
Plant trees on marginal land, maintain production	NI hill	–3%	–12%
	NI intensive	2%	–7%
	SI hill	5%	–8%
	SI intensive	–6%	–10%

Source: Reisinger et al. 2017

* The presented absolute values for profits and greenhouse gas emissions for the 'No mitigation option' are averages across regions.