Manaaki Whenua
Landcare Research

Modelling of agricultural climate change mitigation policy scenarios

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Manaaki Whenua – Landcare Research

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Executive summary

The Ministry for Primary Industries (MPI) commissioned Manaaki Whenua – Landcare Research (MWLR) to model and explore the impact of different climate mitigation scenarios on the agricultural and forestry sectors. This study analyses the economic and environmental impacts of these scenarios under different greenhouse gas (GHG) emission and carbon (in CO_2e) sequestration prices. Specifically, scenarios include different GHG prices, formulations for the proposed 95% free allocation to agriculture, point of obligation, adoption of technological innovations and a GHG reduction target level. All scenarios are analysed for 2020.

Objectives

The objectives of this study are to:

- analyse potential policy options for pricing or regulating GHG emissions from agriculture. These include pricing emissions through an emissions trading system (ETS) or taxes on agricultural emissions and direct regulation through emission reduction targets. We also assess the expected change in emissions if the point of obligation for the policy was placed at either farm level or at processor level;
- assess the potential emissions reductions at several GHG emissions prices;
- assess how the costs and benefits of these scenarios may change depending on the range of available emissions mitigation technologies or changes in management practices;
- assess the impact of different formulations for implementing the 95% free allocation to agriculture.

Methods

To accomplish these study objectives, we use an agri-environmental economic optimisation model – New Zealand Forestry and Agricultural Regional Model (NZFARM). The model simulates five scenarios aimed to reduce biological GHG emissions (methane and nitrous oxide) from agriculture. The impacts of each pricing scenario are assessed for a range of GHG prices (\$25 tCO_2e^{-1}, \$50 tCO_2e^{-1} and \$100 tCO_2e^{-1}). This study does not account for any embodied GHG emissions (e.g. embodied in fertilizer and feed inputs). Landowners can adopt alternative management practices and change land use in all scenarios. We also do not consider the economy-wide effects from change in agricultural and forestry production that might influence the prices, consumption, and trade of these commodities, or their effect on other sectors (e.g. agricultural service sector) and employment.

The modelled scenarios include:

1. *ETS with farmer point of obligation for agricultural emissions and 95% free allocation.* This scenario is based on a farmer's *current* biological GHG emissions (*current* emission refers to emissions in 2020). As there is a 95% free allocation, farmers only face a direct price on 5% of their *current* biological GHG emissions.

Carbon sequestered in forestry receive carbon payments. We model GHG prices of \$25 tCO_2e^{-1}, \$50 tCO_2e^{-1} and \$100 tCO_2e^{-1};

2. *ETS with processor point of obligation for agricultural emissions and 95% free allocation.* This scenario is based on a livestock producer's *current* biological emissions. As specified under the Climate Change Response Act, the processors (e.g. milk and meat processors) are the point of obligation. There is a 95% free allocation and for this scenario processors face a price on 5% of *current* biological GHG emissions from livestock. To implement this scenario, we assume processors pass on these emission costs to their suppliers, i.e. the farmers, by paying a lower price per unit of livestock output. The GHG prices are applied to each tonne of GHG emissions from agricultural product categories such as milk solids, and lamb, beef and deer meat. The GHG emissions per tonne of output (emission factors) are constant across each output categories and were provided by MPI. Using a processor point of obligation is like imposing a GHG levy per tonne of outputs produced. Carbon sequestered in forestry receive a carbon payment. Again, we model GHG prices of \$25 tCO_2e^{-1}, \$50 tCO_2e^{-1} and \$100 tCO_2e^{-1};

3. *ETS with farmer point of obligation for agricultural emissions and decoupled 95% free allocation.* Free allocation in this scenario is based on a methodology whereby a farmer's current production or mitigation decisions do not affect the amount of free allocation they receive. Instead the decoupled free allocation is determined using other methods. For example, the free allocation may be based on a farmer's *historic (i.e. baseline)* biological emissions or could be based on the area of land on different classes (land use capability – LUC). In this scenario, the details of the methodology for determining free allocation are not specified but for the modelling the overall amount of free allocation is equivalent to 95% of the agriculture sector's baseline emissions. Farmers directly pay a price on all current biological GHG emissions but receive a credit based on a decoupled allocation methodology. Therefore, if their current emissions are higher than their credited free allocation, they would have to purchase additional GHG credits to cover that increase. On the other hand, if their current emissions are lower than their credited free allocation, they could sell those credits in the market. Carbon sequestered in forestry receive a carbon payment. Again, we model GHG prices of \$25 tCO_2e^{-1}, \$50 tCO_2e^{-1} and \$100 tCO_2e^{-1};

4. *ETS with farmer point of obligation for agricultural emissions, technological innovations and decoupled 95% free allocation*. As with the previous scenario, farmers directly pay a price on all current biological GHG emissions but receive a credit based on a decoupled methodology. Again, carbon sequestered in forestry receive a carbon payment. GHG emissions are priced at \$25 tCO_2e^{-1}. Technological innovations that reduce GHG emissions while improving/maintaining agricultural productivity are assumed to be available for the dairy sector. Technological innovations included in this scenario are nitrification inhibitors (Carey et al. 2012,

Reisinger & Clark 2016, Reisinger et al. 2018) and a reduction in cow numbers (where cows have increased milk productivity (DairyNZ Economic Group 2018);

5. *Farm-level GHG emissions reduction targets.* This scenario is based on a farmer's *current* biological emissions. A uniform GHG emission reduction target is imposed on all agricultural land uses (excluding forestry) where the reduction target is 6% of 2020 baseline GHG emissions. To aid comparison, the 6% target is based on the GHG emission reductions achieved in the "ETS with farmer point of obligation and decoupled 95% free allocation" scenario with a GHG price of \$25 tCO_2e^{-1}. This scenario does not price the biological GHG emissions, but forestry still receives a payment for any carbon sequestered.

Results

Key results for the modelled scenarios are listed in Table ES1 and discussed below:

ETS with farmer point of obligation for agricultural emissions and 95% free allocation. This scenario has little impact on land use patterns, even at the highest simulated GHG price of \$100 tCO_2e^{-1} (Table 9). While small there is some movement of pastoral land to forestry with smaller areas moving to arable and horticulture uses. At \$25 tCO_2e^{-1} dairy area does increase by about 0.14% at the expense of the drystock sector. Total GHG emissions decrease by 0.3% at GHG prices of \$25 tCO_2e^{-1} and by 12.5% at \$100 tCO_2e^{-1}, compared with the baseline. Sheep and beef adopt some mitigation options, such as removing breeding cows and planting woodlots. Dairy, however, does not adopt any mitigations even at the highest GHG price. The relatively little land use change and low uptake of mitigation options is primarily due to farmers facing only 5% of the cost of their current biological GHG emissions. Net agricultural and forestry revenue falls by 0.5% (\$47 million) at \$25 tCO_2e^{-1} and by 1.2% (\$132 million) at \$100 tCO_2e^{-1}.

ETS with processor point of obligation for agricultural emissions and 95% free allocation. As with the previous scenario, the ETS with processor point of obligation leads to small changes in land use area as processors only pay for (and pass onto farmers) the cost of 5% of biological GHG emissions. Small areas of pastoral land does move into horticulture, arable and forestry land uses. At \$25 tCO_2e^{-1} dairy area increases by 0.07%. Total GHG emissions are reduced by 0.3% (106,000 tonnes) at \$25 tCO_2e^{-1} and 12.2% (5 million tonnes) at \$100 tCO_2e^{-1}. The sheep and beef sector remove breeding cows and plant woodlots, but dairy does not adopt any mitigations options in response to the pricing of GHG emissions. Net agricultural and forestry revenue decreases by 0.4% (\$32 million) at \$25 tCO_2e^{-1} and by 0.9% (\$94 million) at \$100 tCO_2e^{-1}. There are differences in net revenue observed between the processor- and farm-level points of obligation. For the processor, the same GHG emissions factor is applied to each unit of similar output regardless of differences in farm system and location. However, the farm-level accounts for the variability in the GHG emissions that arise from differences between farm systems. It is this specified emissions factor versus farm system emissions that drives the difference between these scenarios.

ETS with farmer point of obligation for agricultural emissions and decoupled 95% free allocation. Decoupling the 95% free allocation from current emissions leads to substantial impacts on the area in different land uses. As the free allocation is not tied to current emissions, farmers face the full cost of their current biological emissions. There is a net payment back to the sector for the 95% free allocation, but our modelling does not specify how this payment is returned to individual farmers. Instead, there is a lump sum transfer back to the agricultural sector. Therefore, farmers do not get a direct signal of any reduced payment obligation. Pastoral land uses shift into forestry, arable, and horticulture land uses and these changes are more pronounced as GHG prices increase. At the highest GHG price, the dairy area declines by about 17% while sheep and beef area decreases by around 16%. The forestry area increases by up to 80% (1.8 million ha), as there are payments for carbon sequestration. This scenario encourages dairy and sheep and beef farmers to adopt GHG mitigation practices and at \$100 tCO_2e^{-1} 78% of the sheep and beef area has woodlots planted on a portion of their land. Total GHG emissions are reduced by 6% (2.5 million tonnes) at \$25 tCO_2e^{-1} and by 35% (14.4 million tonnes) at \$100 tCO_2e^{-1}. The pastoral sector sees large reductions in net revenue – approximately 20% (\$1.15 billion) at \$25 tCO_2e^{-1} and by 66% (\$3.7 billion) at \$100 tCO_2e^{-1}. However, decoupling the 95% free allocation from current emissions resulted in an increase in overall net agricultural revenue as the agricultural sector receives a credit for 95% of their historic emissions. At \$25 tCO_2e^{-1}, this translates to a small increase in net revenue (0.2%) which further increases to about 18% at \$100 tCO_2e^{-1}.

ETS with farmer point of obligation for agricultural emissions, technological innovations and decoupled 95% free allocation. Technological innovations reduce the impact on net revenue from pricing agricultural biological emissions. 59% of the dairy area reduces cow numbers (where the cows were assumed to have higher milk production), but only 0.3% used nitrification inhibitors due to its relatively high cost. With these new mitigation technologies, the decrease in dairy area and net revenue are less than the same scenario without technological innovations. Area and net revenue remain unchanged for other pastoral land uses as there were no new technologies available to those sectors. Net revenue from forestry, arable and horticultural sectors increase given the shift away from pastoral land uses to these land uses. However, these gains are smaller than in the previous scenario without technological innovations as less dairy land area shifts into these land uses. Decoupling the 95% free allocation from current emissions results in a 2% increase in overall net revenue. The larger increase in net revenue results from the new mitigation technologies reducing biological emissions and therefore the cost of emissions for the dairy sector. GHG emissions decrease by 8% whereas the net GHG emissions with forestry sequestration included decrease by 78%.

Farm-level GHG emissions reduction target. Imposing a uniform GHG emission reduction target of 6% below baseline biological emission levels reduces the area of pastoral land uses. The reduction target achieves the same emissions reduction as the \$25 tCO_2e^{-1} GHG price with a farmer point of obligation and decoupled 95% free allocation. Some pastoral land moves to forestry, arable, and horticulture. Deer has the largest (relative) decrease,16%, in area while forestry increases in area by 17%. There is also some adoption of mitigation options by dairy and sheep and beef land uses. There is a small reduction of 0.05% in net revenue.

Table ES1: Estimated change in net revenue and total GHG emissions for the modelled scenarios (percentage change compared with the 2020 baseline scenario)

Scenarios	Net revenue (% change)			GHG emissions (% change)		
	$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}	$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
ETS - farmer point of obligation (95% free allocation)	–0.5	–0.6	–1.2	–0.3	–3.2	–12.5
ETS - processor point of obligation (95% free allocation)	–0.4	–0.5	–0.9	–0.3	–3.1	–12.2
ETS - farmer point of obligation (decoupled 95% free allocation)	0.2	3.4	18	–6	–18	–35
ETS - farmer point of obligation, and technological innovations (decoupled 95% free allocation)	2			–8		
Farm-level GHG emissions reduction targets (GHG price only applied to forestry)	–0.05			–6		

1 Introduction

The Ministry for Primary Industries (MPI) commissioned an analysis of the potential policy options for pricing or regulating greenhouse gas (GHG) emissions from agriculture. This was an assessment of the potential emissions reductions for different scenarios at three emissions prices and how the impacts may change depending on the range of available emissions mitigation technologies. We analyse economic and environmental impacts of climate change mitigation policy scenarios on the agricultural and forestry sectors under different GHG emission and carbon (in CO_2e) sequestration prices. We considered biological GHG emissions (methane and nitrous oxide) and carbon sequestration in this analysis.

For this analysis, we use an agri-environmental economic optimisation model – New Zealand Forestry and Agricultural Regional Model (NZFARM). A nationwide analysis of land use change, adoption of management practices to reduce GHG emissions, net agricultural and forestry revenues, GHG emissions, carbon sequestration, and agricultural production was undertaken.

2 Methods

2.1 NZFARM model

We use NZFARM to assess the economic impacts of agricultural climate change mitigation policy scenarios. NZFARM was developed through the Sustainable Land Management and Climate Change Research Programme (SLMACC) and has been used to assess climate and water quality scenarios across New Zealand (Daigneault et al. 2012, 2017; Djanibekov et al. 2018).

NZFARM is a comparative static model that can account for all major farming and land use types in New Zealand. It maximizes the net revenue from agricultural/forestry production subject to feasible land use area and environmental constraints.

NZFARM facilitates a 'what if' scenario analysis by showing how changes in environmental policy (e.g. GHG emission prices) could affect the uptake of agricultural mitigation options, changes in land use, and any subsequent spill-over effects on a group of performance indicators important to decision-makers and stakeholders. The what if scenario analyses are performed by solving for a baseline, or status quo, economic optimal condition, then imposing specific policies or other changes on the system and solving the model again to compute a new economic optimal condition consistent with the scenario.

Performance indicators tracked within NZFARM for this analysis include economic (e.g. net revenue, production) and environmental (e.g. carbon sequestration and GHG emissions for all land uses) variables.

The model includes the following land uses: dairy, sheep and beef, deer, arable, forestry, fruits, pipfruit, vegetables, viticulture, native, and other type of land uses (e.g. urban land area). Dairy includes five different systems distributed across New Zealand. For the sheep and beef sector, we consider six systems/types classified according to topography and management practices. Forestry sequesters carbon and produces timber; however timber production could not be derived from the Forest Investment Framework (FIF; Harrison et al. 2017) outputs and so was not included (see section 2.3). Figure 1 depicts the structure of NZFARM model.

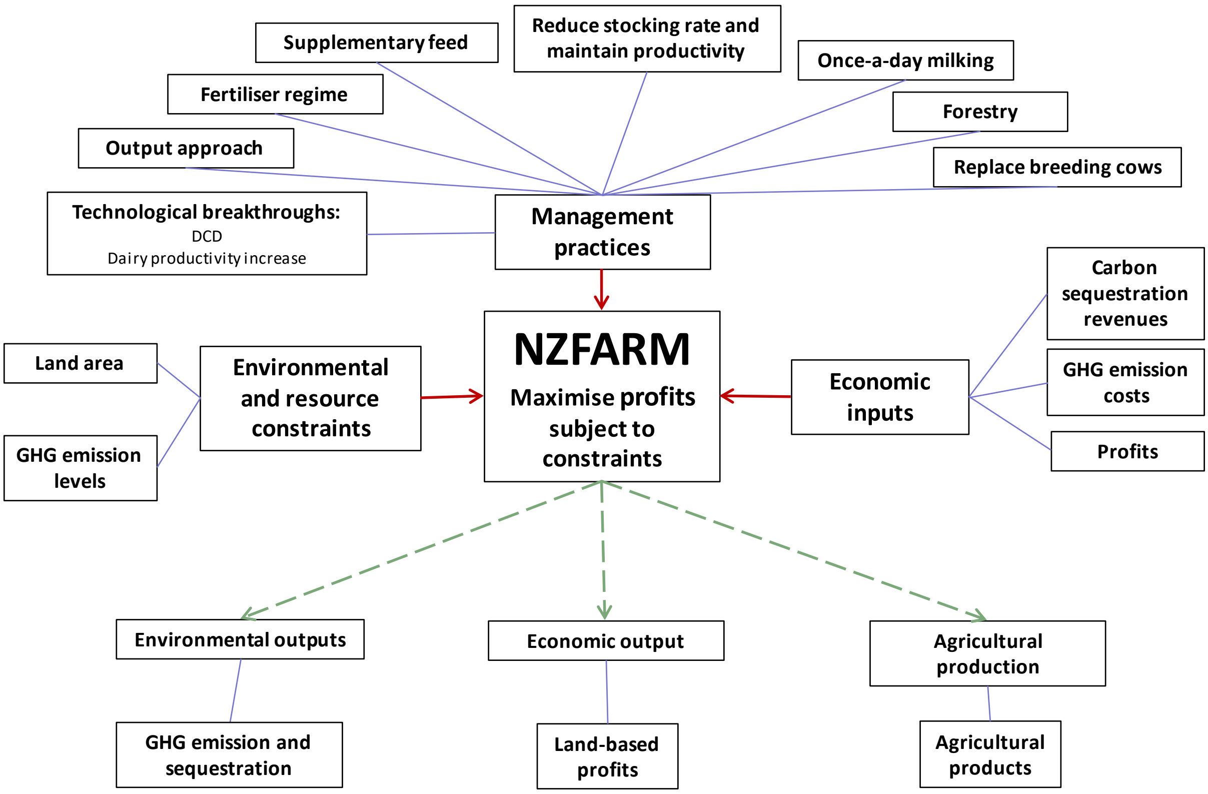

Figure 1: NZFARM model structure. Source: Modified from Daigneault et al. (2017).

2.2 On-farm management practices

The NZFARM model includes different on-farm GHG management practices (mitigation options) for dairy (Table 1; Djanibekov et al 2018). Mitigation options include the output approach (i.e. farm-specific changes targeting nitrogen fertilizer, supplementary feed, and stocking rate to reduce GHG emissions), reduction in fertilizer use, change in supplemental feed, reduction in cow numbers with no change in milk production per cow, once-a-day milking, and planting forestry (i.e. woodlots) on parcels of their land (DairyNZ Economic Group 2017, 2018). The new woodlots can sequester carbon. These economic and environmental indicators for dairy differ with dairy system, intensity of management practices, and regions. We assumed the change in sheep and beef (meat and wool) outputs under the different mitigations was proportional to the change in net revenue. Summary statistics for GHG emissions, net revenue and milk output of dairy under different management practices are given in the Appendix 1 (Table 46 and Table 47).

Table 1: Description of management practices considered for dairy

Management practice	Description	Intensities of management practices			
		a	b	c	d
(1) Output approach reducing GHG emissions	Farm-specific, cost-effective farm system changes targeting nitrogen (N) fertilizer, 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 fertilizer use	N fertilizer reductions, then reduce stocking rate to match feed supply and demand	25% decrease in N fertilizer	50% decrease in N fertilizer	75% decrease in N fertilizer	100% decrease in N fertilizer
(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 fertilizer 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

Source: DairyNZ Economic Group (2017, 2018).

Sheep and beef mitigation options are based on Reisinger et al. (2017) as part of the Biological Emissions Reference Group (BERG) work and include reducing stocking rate while maintaining production, removing of breeding cows, and planting forestry on pastoral land (Table 2). These management practices have different intensities. Areas of forestry (i.e. woodlots) can also be planted on sheep and beef farms to sequester carbon. Based on discussions with farm system experts at Beef + Lamb New Zealand, there is only the capacity to remove breeding cows on approximately 5% of the baseline sheep and beef area. This is because, where feasible, most breeding cows have already been removed. GHG and net revenue of sheep and beef under different management practices are given in Appendix 1 (Table 49).

Table 2: Description of management practices considered for the sheep and beef sector

Mitigation option	Description
Reduction in stocking rate and maintain production	Stocking rates reduced, while sheep and beef production remain 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

Source: Reisinger et al. (2017).

2.3 Data Sources

Economic and environmental indicators for pastoral, arable and horticultural land uses used in this study are primarily based on data compiled for the 2018 BERG project (Djanibekov et al. 2018).

Distribution of farm systems

The baseline for this analysis is 2020 and the areas in pastoral, arable and horticultural land uses were estimated from the Dorner et al. (2018) projection of future land use areas using Motu's Land Use in Rural New Zealand model (LURNZ). Information from DairyNZ, Beef + Lamb New Zealand, FIF model (Harrison et al. 2017), national land cover data, land use capability and other secondary data sources were used to compile the initial 2012 land use areas for this projection that included a distribution of dairy and sheep and beef farm systems within each region.

Forestry

As requested by MPI, modelling results from the FIF (Harrison et al. 2017) was used to parameterise the forestry sector for this analysis. The FIF provides data on land expectation value, and carbon revenue and combined revenue from carbon and timber at $25 tCO_2e^{-1}. From the carbon revenue, we were able to derive the amount of C sequestered by forestry using the carbon price. However, as the combined carbon and timber revenue also included the cost of land purchase, we were unable to derive the amount of timber produced. Therefore, timber production is not included in this analysis.

Dairy

The farm systems for each region were provided by DairyNZ and we used DairyNZ 2017 dairy farm budgets in this analysis (Djanibekov et al. 2018; DairyNZ Economic Group 2017, 2018). This dataset includes a range of farm management practices and the corresponding net revenues, GHG emissions and nutrient (nitrogen and phosphorous) losses. All dairy environmental parameters are estimated using Overseer. Only the methane and nitrous oxide emissions were used as the CO_2 emissions include embodied carbon for some inputs.

Sheep and beef

The farm systems for sheep and beef are based on Beef + Lamb regional farm systems and we use Beef + Lamb New Zealand 2017 sheep and beef farm budgets (Beef+Lamb New Zealand, 2017). The GHG emissions for the sheep and beef sector were estimated using the New Zealand GHG inventory methodology (MfE 2017). Stocking rate and fertilizer application levels are the key data requirements to estimate the GHG emissions from this sector. There are no corresponding nutrient budgets for sheep and beef farming systems.

Other land uses

The horticultural farm budgets are from Horticulture New Zealand (Djanibekov et al. 2018) while the arable cropping farm budgets are based on Daigneault et al. (2017). The deer farm budgets are from Daigneault et al (2018). The GHG emissions from these sectors were estimated using the New Zealand GHG inventory methodology (MfE 2017). There are no associated nutrient budgets for these other land uses.

Processor-level GHG emissions

The GHG emission factors for milk solids, and beef, lamb and deer meat outputs were specified by MPI (Joel Gibbs, MPI, personal communication, 31 January 2019). These factors are outlined in the section that describes the scenarios.

Technological innovations

There are two technical or management innovations (hereafter called "technological innovations") considered in this analysis – nitrification inhibitors (DCD) and improved dairy cow productivity. Although these technologies already available, they are considered innovative as farmers are not implementing these technologies. The economic and environmental impacts of nitrification inhibitor technology are based on published literature (Reisinger & Clark 2016). The impact of reducing dairy cow numbers while increasing milk production per cow was sourced from the DairyNZ Economic Group (Djanibekov et al. 2018).

2.4 Assumptions and caveats

Some of the key assumptions in the analysis include:

- there have been no responses to other national or regional policies, such as the National Policy Statement for Freshwater Management (NPSFM). This was to isolate the effects of the climate mitigation policy scenarios.
- economic and environmental parameters of forestry are distributed by LUC classes as are pastoral, arable, and horticultural land uses.
- there is no uptake of the GHG mitigation practices in the baseline. However, where industry have indicated there are constraints to the uptake of some practices these are included for the scenarios. For instance, Beef + Lamb New Zealand noted that

breeding cows have already been removed from most areas where this is feasible. Therefore, we only allow for an additional 5% of breeding cows to be removed.

- forestry will continue to receive a carbon sequestration payment.

Some points to note for the analysis include:

- in the scenarios, land conversion costs (e.g. conversion from sheep and beef to forestry) are not included as it is not possible to determine which land uses converted to another use. Rather aggregate areas of different land uses and the changes are tracked.
- forestry net revenue does not include timber sales as it was not possible to derive timber production or timber sales from the outputs of the FIF.
- only biological emissions and carbon sequestration are included in the analysis. CO_2 emissions associated with agricultural emissions are excluded as most of these emissions are fossil emissions and already accounted for in the ETS. Lime and organic soil emissions could be an exception, but the farm systems included in the modelling did not apply lime and we did not account for organic soils. Also, dairy GHG emissions were estimated using Overseer and CO_2 emissions in Overseer include embodied carbon of some inputs.

2.5 Scenarios

2.5.1 Baseline

The baseline for this analysis is 2020 and was projected using LURNZ (Dorner et al. 2018). As future carbon prices are not known with certainty we generated three projected baselines that correspond to three potential GHG prices – \$25 tCO_2e^{-1}, \$50 tCO_2e^{-1} and \$100 tCO_2e^{-1} – that the forest sector could receive under the emissions trading scheme (ETS) for the carbon the sector sequesters. In the modelling of the scenarios, the 2020 \$25 tCO_2e^{-1} baseline is used where the GHG price is \$25 tCO_2e^{-1}, the 2020 \$50 tCO_2e^{-1} baseline is used where the GHG price is \$50 tCO_2e^{-1} and the 2020 \$100 tCO_2e^{-1} baseline is used where the GHG price is \$100 tCO_2e^{-1}.

To enable us to isolate the effects of the climate change mitigation policy scenarios, we do not include policies implemented post-2012 into the baseline (e.g. NPSFM).

Table 3 shows the 2020 baseline or 'business as usual' land use area, net revenue, GHG emissions/carbon sequestration. This table shows the 2020 baselines for forestry where the net revenues are reported for GHG prices of \$25 tCO_2e^{-1}, \$50 tCO_2e^{-1}, and \$100 tCO_2e^{-1}. Table 4 provides information on agricultural production in the 2020 baseline. As noted above, it was not possible to derive timber production from the FIF model output and so timber output is not reported in this table. Table 5 shows methane (CH_4) and nitrous oxide (N_2O) emissions from dairy and sheep and beef sectors.

Table 3: Total land use area, net revenue and GHG emissions, 2020 baseline

Land-use category	Land-use area (1,000 ha)	Net revenue ($ million)	GHG emissions (1000 tCO_2e^{-1})
2020 baseline			
Dairy	2,098	2,808	15,825
Sheep and beef	8,263	2,702	24,043
Deer	214	125	778
Arable	341	563	341
Fruits	38	278	10
Pipfruit	16	101	1
Vegetables	37	442	14
Viticulture	42	666	3
Native	9,179	n.a.	n.a.
Other	4,188	n.a.	n.a.
2020 baseline for forestry at differing carbon prices			
Forestry with $25 tCO_2^{-1} for carbon sequestration	2,223	1,211	–29,232
Forestry with $50 tCO_2^{-1} for carbon sequestration	2,223	1,941	–29,232
Forestry with $100 tCO_2^{-1} for carbon sequestration	2,223	3,403	–29,232

n.a. means the information is not available; negative values in forestry GHG emissions represents carbon sequestration; we project three baselines that correspond to a $25 tCO_2e^{-1}, $50 tCO_2e^{-1}, and $100 tCO_2e^{-1} payment for carbon sequestration in forestry.

Table 4: Total agricultural production, 2020 baseline

Commodities	Output (1,000 t)
Milk solid	1,554
Beef	424
Lamb	502
Deer	47
Wool	166
Wheat	1,024
Barley	853
Maize	1,422
Berries	100
Grapes	483
Pipfruit	42
Kiwifruit	79
Vegetables	1,463

Note: It was not possible to derive timber production from the FIF output and so timber output is not reported

Table 5: Total CH_4 and N_2O emissions, 2020 baseline

Land uses	CH_4 emissions (1,000 t CH_4)	N_2O emissions (1,000 t N_2O)
Dairy	450	15
Sheep and beef	634	27

2.5.2 Policy scenarios

We assessed five agricultural climate change mitigation scenarios to estimate the impact of these policy scenarios on New Zealand's agricultural and forestry sectors (Table 6). In each scenario, impacts on agricultural and forestry net revenue and GHG emissions are estimated for 2020. For three of the five scenarios, we also include three GHG emission prices ($25 tCO_2e^{-1}, $50 tCO_2e^{-1}, and $100 tCO_2e^{-1}). Carbon sequestration related to forestry activities also receives a payment based on the GHG price. Hence, net revenues may fall because emissions are priced with some of this cost offset by carbon sequestration payments. In all scenarios farmers can adopt alternative management practices to reduce their GHG emissions and in one scenario there are two technological innovations available. The model optimises across land uses and includes land-use change.

This study analyses the following five policy scenarios:

1. *ETS with farmer point of obligation for agricultural emissions and 95% free allocation.* This scenario is based on a farmer's *current* biological GHG emissions. As there is a 95% free allocation, farmers only face a direct price on 5% of their *current* biological GHG emissions. Carbon sequestered in forestry receive a carbon payment. We model GHG prices of $25 tCO_2e^{-1}, $50 tCO_2e^{-1} and $100 tCO_2e^{-1};

2. *ETS with processor point of obligation for agricultural emissions and 95% free allocation.* This scenario is based on a livestock producer's *current* biological emissions. As specified under the Climate Change Response Act, the processors (e.g. milk and meat processors) are the point of obligation. There is a 95% free allocation and for this scenario processors face a price on 5% of *current* biological GHG emissions from livestock. To implement this scenario, we assume processors pass on these emission costs to their suppliers, i.e. the farmers, by paying a lower price per unit of livestock output. The GHG prices are applied to each tonne of GHG emissions from agricultural product categories such as milk solids, and lamb, beef and deer meat. The GHG emissions per tonne of output (emission factors) are constant across each output categories and are provided by MPI (Joel Gibbs, MPI, personal communication, 31 January 2019). These emission factors are: 8.79 tCO_2e^{-1} per tonne of milk solid; 14.2 tCO_2e^{-1} per tonne of beef meat; 14.2 tCO_2e^{-1} per tonne of lamb meat; and 21 tCO_2e^{-1} per tonne of deer meat. Using a processor point of obligation is like imposing a GHG levy per tonne of outputs produced. C) sequestered in forestry receive a carbon payment. Again, we model GHG prices of $25 tCO_2e^{-1}, $50 tCO_2e^{-1} and $100 tCO_2e^{-1};

3. *ETS with farmer point of obligation for agricultural emissions and decoupled 95% free allocation.* This scenario is based on an allocation methodology that is decoupled from farmer's *current* biological emissions. Farmers directly pay a price on all current biological GHG emissions but receive a credit based on the decoupled allocation methodology (e.g. based on historic emission or land use capability). Therefore, if their current emissions are higher than their credited free allocation, they purchase additional GHG credits to cover that increase. On the other hand, if their current emissions are lower than their credited free allocation, they could sell those credits in the market. Carbon sequestered in forestry receive a carbon payment. Again, we model GHG prices of \$25 tCO_2e^{-1}, \$50 tCO_2e^{-1} and \$100 tCO_2e^{-1};

4. *ETS with farmer point of obligation for agricultural emissions, technological innovations and decoupled 95% free allocation.* This scenario is based on de-coupling the allocation methodology from a farm's current biological emissions. Farmers directly pay a price on all current biological GHG emissions but receive a credit based on the allocation methodology. The overall size of this free allocation corresponds with 95% of the sector's historic baseline emissions. Again, there is a payment for carbon sequestered by forestry. GHG emissions are priced at \$25 tCO_2e^{-1}. Technological *innovations* that reduce GHG emissions while improving/maintaining agricultural productivity are assumed to be available for the dairy sector. Technological innovations included in this scenario are nitrification inhibitors (Carey et al. 2012; Reisinger & Clark 2016; Reisinger et al. 2018) and a reduction in cow number (where cows have increased milk productivity (DairyNZ Economic Group 2018)). Nitrification inhibitors increase milk production by 1.4% and 0.9% in the South and North Island, respectively (Carey et al. 2012). We also assume that nitrification inhibitors reduce N_2O emissions by 60% and cost \$250 ha^{-1} (Reisinger & Clark 2016; Reisinger et al. 2018). Reducing cow numbers does decrease total milk production but the dairy net revenue per hectare increases due to the lower costs associated with less cows. Information on economic and environmental impacts of these technologies are given in Appendix 2 (Table 50, Table 51, and Table 54);

5. *Farm-level GHG emission reduction target.* In this scenario, a uniform GHG emission reduction target of 6% below baseline biological emission levels is imposed on all agricultural land uses (excluding forestry). The reduction target is the same emissions reduction achieved at a \$25 tCO_2e^{-1} GHG price with farmer point of obligation and decoupled 95% free allocation. This scenario does not price the biological GHG emissions, but forestry still receives a payment for any carbon sequestered.

Table 6: Modelled policy scenarios

Scenario	GHG prices	Assumptions
ETS with farmer point of obligation and 95% free allocation	• \$25 tCO_2e^{-1} • \$50 tCO_2e^{-1} • \$100 tCO_2e^{-1}	Farmers pay a price on 5% of *current* biological GHG emissions. Carbon sequestered by forestry receives a payment 95% free allocation included
ETS with processor point of obligation and 95% free allocation	• \$25 tCO_2e^{--1} • \$50 tCO_2e^{-1} • \$100 tCO_2e^{-1}	Processors pay a price on 5% of *current* GHG emissions from livestock products such as milk solids, and lamb, beef and deer meat Emission factors for livestock product categories are specified by MPI 95% free allocation included. Carbon sequestered by forestry receives a payment
ETS with farmer point of obligation and decoupled 95% free allocation	• \$25 tCO_2e^{-1} • \$50 tCO_2e^{-1} • \$100 tCO_2e^{-1}	Farmers pay a price on *current* biological GHG emissions 95% free allocation is decoupled, receive a payment based on allocation methodology. Carbon sequestered by forestry receives a payment
ETS with farmer point of obligation, technological innovations and decoupled 95% free allocation	• \$25 tCO_2e^{-1}	Technological innovations for reducing GHG emission while improving/maintaining agricultural productivity are available to dairy sector Farmers pay a price on *current* biological GHG emissions 95% free allocation is decoupled, based on allocation methodology Carbon sequestered by forestry receives a payment
Farm-level GHG emissions reduction target	• \$25 tCO_2e^{-1} (only applied to C sequestered through forestry)	A uniform 6% GHG emission reduction target is imposed on all agricultural land uses Biological emissions are not priced Carbon sequestered by forestry receives a payment

3 Results

The results of this study show the impacts of five scenarios aimed to reduce biological GHG emissions. In Table 7 and Table 8, we present the summary of overall relative changes in net revenue and GHG emissions by land use, under different scenarios. The results show that the ETS with 95% free allocation slightly reduces net revenue but is not very effective at reducing GHG emissions at \$25 tCO_2e^{-1}. Even at higher GHG prices there is only a small reduction in GHG emissions. Decoupling the 95% free allocation from current emissions results in greater reductions in GHG emission. As the agricultural sector faces the full prices of their current GHG emissions and then receives a credit for 95% of their historic emissions the net agricultural and forestry revenues increase for all GHG prices. Technological innovations with a decoupled free allocation results in the largest GHG emission reductions at \$25 $tCO_2e^{-1}$and also increases net revenue. The GHG emission reduction target achieves the same GHG emission reduction as at \$25 $tCO2e^{-1}$ GHG price with farmer point of obligation and decoupled 95% free allocation (as this is what the target was based on) and has a small negative impact on net revenue.

Table 7: Relative change in net revenue from the baseline, modelled policy scenarios

Scenarios	Simulation results (% change)		
	\$25 tCO_2e^{-1}	**\$50 tCO_2e^{-1}**	**\$100 tCO_2e^{-1}**
ETS with farmer point of obligation (95% free allocation)	–0.5	–0.6	–1.2
ETS with processor point of obligation (95% free allocation)	–0.4	–0.5	–0.9
ETS with farmer point of obligation (decoupled 95% free allocation)	0.2	3.4	18
ETS with farmer point of obligation, and technological innovations (decoupled 95% free allocation)	2		
Farm-level GHG emissions reduction targets (GHG price only applied to forest carbon sequestration)	–0.05		

Table 8: Relative change in GHG emissions from the baseline, modelled policy scenarios

Scenarios	Simulation results (% change)		
	\$25 tCO_2e^{-1}	**\$50 tCO_2e^{-1}**	**\$100 tCO_2e^{-1}**
ETS with farmer point of obligation (95% free allocation)	–0.3	–3.2	–12.5
ETS with processor point of obligation (95% free allocation)	–0.3	–3.1	–12.2
ETS with farmer point of obligation (decoupled 95% free allocation)	–6	–18	–35
ETS with farmer point of obligation, and technological innovations (decoupled 95% free allocation)	–8		
Farm-level GHG emissions reduction targets (GHG price only applied to carbon sequestration)	–6		

3.1 ETS with farmer point of obligation for agricultural emissions and 95% free allocation

3.1.1 Land use

This scenario has little impact on land use, even at the highest simulated GHG price of $100 tCO_2e^{-1} (Table 9). Small areas of pastoral land shifts mainly to forestry with smaller areas moving to arable and horticulture uses. Also, as the net revenue for the dairy sector is high, some area (0.1%) moves into dairy at the lowest GHG price. However, converting to dairy is costly (Matheson 2016), which might mean that if conversion costs were included then these conversions may not happen. As GHG prices increase more pastoral land is converted to lower GHG emitting land uses with higher net revenues. At $100 tCO_2e^{-1} about 0.8% (66,000 ha) of sheep and beef land and 0.4% (8,000 ha) of dairy land moves to other land uses, and the area in forestry increases by about 3.7% (82,000 ha). It should be noted that while the directional changes in the land use area due to increases in GHG prices are consistent, these changes are non-linear.

Table 9: Land use area, ETS with farmer point of obligation and 95% free allocation

Land uses	Baseline (1,000 ha)	Simulation results (% change)		
		$25 tCO_2e^{-1}	**$50 tCO_2e^{-1}**	**$100 tCO_2e^{-1}**
Arable	341	0.03	0.3	0.5
Fruits	38	0.04	0.3	0.9
Vegetables	37	0.05	0.7	1.2
Pipfruit	16	0.04	0.3	0.8
Viticulture	42	0.05	0.9	1.4
Forestry	2,223	0.4	0.6	3.7
Dairy	2,098	0.1	–0.003	–0.4
Sheep and beef	8,263	–0.1	–0.1	–0.8
Deer	214	–0.8	–2.5	–5.2

Sheep and beef adopt some mitigation options, such as removing breeding cows and planting woodlots (Table 10). 3% of sheep and beef land adopt mitigation options at $25 tCO_2e^{-1} which increases to 37% at 100 $ tCO_2e^{-1}. Mitigation options are adopted because their adoption generates larger returns in this scenario for some farm systems in certain regions than adopting no mitigation options (see Appendix 1 for costs and benefits of management practices). However, at higher GHG prices the sheep and beef sector plants more woodlots and reduces the removal of breeding cows. This is primarily because of the income generated from forest carbon sequestration. Dairy, however, does not adopt any mitigation options even at the highest GHG price.

The relatively little land use change and low uptake of mitigation options is primarily due to farmers facing only 5% of the cost of their current biological GHG emissions. For example, at $25 tCO_2e^{-1} this would be equivalent to a GHG levy of $1.25 tCO_2e^{-1}. This is a small cost considering the GHG emissions and net revenues from agricultural land uses.

Table 10: Land use area by management practices, ETS with farmer point of obligation and 95% free allocation

Management practice	Simulation results (1,000 ha)		
	$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Dairy			
No mitigation	2,100	2,098	2,090
Output approach	0	0	0
Reduction in fertilizer use	0	0	0
Change in supplementary feed	0	0	0
Reduction in cow numbers and same milk production per cow	0	0	0
Once-a-day milking	0	0	0
Planting forestry	0	0	0
Sheep and beef			
No mitigation	8,024	6,967	5,179
Reduction in stocking rates	0	0	0
Removal of breeding cows	2.8	2.6	2.2
Planting forestry	225	1,283	3,015

3.1.2 Net revenue

Results show that the net agricultural and forestry revenues do not fall by much as farmers face only 5% of the cost of their biological emissions. At $25 tCO_2e^{-1} GHG price the aggregated net revenues decrease by 0.5% ($47 million) and by 1.2% ($132 million) at $100 tCO_2e^{-1}, compared with the baseline. Deer, followed by sheep and beef, have the largest percentage decrease in net revenue among land uses compared with the baseline, across all GHG prices (Table 11). For instance, at $25 tCO_2e^{-1}net revenue from deer reduce by 1.6% (about $2 million) and sheep and beef reduce by 1.2% ($32 million). At $100 tCO_2e^{-1}, net revenues further reduce for deer and sheep and beef. These changes are driven by the decrease in land in these uses and cost of their GHG emissions (Table 9). Profits from dairy also declines across all GHG prices. At the highest GHG price of $100 tCO_2e^{-1} the net revenues from dairy falls by 3.5% ($98 million) compared with the baseline. At higher GHG prices, more area is allocated to arable and horticultural uses and its net revenues are accordingly larger than in the baseline. Despite the conversion of some pastoral land to arable and horticultural uses the cost of GHG emissions still results in a decline in total net revenue even at $25 tCO_2e^{-1}. Net revenue from forestry also increase due to the increase in forest area and the revenue from carbon sequestration.

Table 11: Net revenue, ETS with farmer point of obligation and 95% free allocation

Land uses	Baseline ($ millions)	Simulation results (% change)		
		$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Arable	563	–0.05	0.2	0.3
Fruits	278	0.03	0.3	0.9
Vegetables	442	0.06	0.9	1.2
Pipfruit	101	0.05	0.4	1
Viticulture	666	0.06	1.1	1.4
Forestry net revenue for baseline at $25 tCO_2e^{-1}	1,211	0.4	n.a.	n.a.
Forestry net revenue for baseline at $50 tCO_2e^{-1}	1,941	n.a.	0.6	n.a.
Forestry net revenue for baseline at $100 tCO_2e^{-1}	3,403	n.a.	n.a.	2.7
Dairy	2,810	–0.7	–1	–3.5
Sheep and beef	2,695	–1.2	–1.5	–5
Deer	125	–1.6	–4	–8.2
Total net revenue for baseline at $25 tCO_2e^{-1}	**8,891**	**–0.5**	**n.a.**	**n.a.**
Total net revenue for baseline at $50 tCO_2e^{-1}	**9,626**	**n.a.**	**–0.6**	**n.a.**
Total net revenue for baseline at $100 tCO_2e^{-1}	**11,083**	**n.a.**	**n.a.**	**–1.2**

Note: There are three 2020 baselines, a different baseline for each of the GHG prices as there is already a payment for the carbon sequestered by forestry; n.a. denotes where there are no values.

3.1.3 GHG emissions and carbon sequestration

Carbon sequestration from the larger forestry area increases across all GHG prices (Table 12). At $25 tCO_2e^{-1}, forestry sequestration increases by 2% and at $100 tCO_2e^{-1} it increases by 20%. This increase comes from new forest plantations and woodlots planted as mitigation options on sheep and beef land. The sheep and beef sector sees the largest reduction in GHG emissions among pastoral land uses because of land use change and the uptake of mitigation options (particularly planting of woodlots). Sheep and beef farms sequester about 467,000 tCO_2e^{-1} annually through planting woodlots at $25 tCO_2e^{-1} GHG price. At $50 tCO_2e^{-1} and $100 tCO_2e^{-1}, woodlots on sheep and beef farms sequester about 3 million tCO_2e^{-1} and 5 million tCO_2e^{-1}, respectively. There is also a reduction in total GHG emissions from deer, because of reduced area. Dairy sector GHG emissions increase slightly at $25 tCO_2e^{-1}, but at higher GHG prices there is a move out of dairy and there are corresponding decreases in their emissions. An increase in arable and horticultural area also leads to an increase in their emissions. Total GHG emissions decrease by 0.3% at $25 tCO_2e^{-1} and by 12.5% at $100 tCO_2e^{-1}. Net GHG emissions decrease between 6% and 93% for $25 tCO_2e^{-1} and $100 tCO_2e^{-1}, respectively.

Table 12: Total GHG emissions and carbon sequestration, ETS with farmer point of obligation and 95% free allocation

Land uses	Baseline (1,000 $tCO_2 e^{-1}$)	Simulation results (% change)		
		$25 tCO_2e^{-1}	**$50 tCO_2e^{-1}**	**$100 tCO_2e^{-1}**
Arable	341	0.03	0.3	0.5
Fruits	10	0.04	0.3	0.9
Vegetables	14	0.08	1.1	1.3
Pipfruit	1	0.05	0.4	0.8
Viticulture	3	0.03	0.6	1.3
Dairy	15,825	0.06	–0.1	–1.3
Sheep and beef	24,043	–0.5	–5.3	–20.4
Deer	778	–0.9	–2.8	–4.8
Forestry	–29,232	2	11	20
Gross CO_2 emissions	**41,016**	**–0.3**	**–3.2**	**–12.5**
Total net GHG emissions	**11,784**	**–6**	**-38**	**–93**

Note: *negative value for forestry represents CO_2 sequestration levels. Forestry sequestration also includes carbon sequestration from planting woodlots on dairy and sheep and beef land.

The increase in dairy area increases its CH_4 and N_2O emissions at the lowest GHG price. However, at higher prices these emissions decrease by up to 2% (Table 13 and Table 14). Across all GHG prices, the biological emissions from the sheep and beef sector decreases as land area in sheep and beef decreases and the sector adopts mitigation options. Overall, there is a reduction of total CH_4 and N_2O emissions at all three GHG prices. At $25 tCO_2e^{-1} total CH_4 and N_2O emission levels are both reduced by 0.5% from the baseline. At $100 tCO_2e^{-1}, CH_4 and N_2O emission levels reduce by 12% and 15%, respectively.

Table 13: Total CH_4 emissions, ETS with farmer point of obligation and 95% free allocation

Land uses	Baseline (1,000 t CH_4)	Simulation results (% change)		
		$25 tCO_2e^{-1}	**$50 tCO_2e^{-1}**	**$100 tCO_2e^{-1}**
Dairy	450	0.06	–0.05	–0.9
Sheep and beef	634	–0.9	–8	–19
Total CH4 emissions	**1,085**	**–0.5**	**–5**	**–12**

Table 14: Total N_2O emissions, ETS with farmer point of obligation and 95% free allocation

Land uses	Baseline (1,000 t N_20)	Simulation results (% change)		
		$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Dairy	15	0.05	–0.3	–2
Sheep and beef	27	–0.8	–7	–23
Total N2O emissions	**43**	**–0.5**	**–4**	**–15**

3.1.4 Agricultural production

Production of beef, lamb and deer meat and wool reduce (Table 15) because the area in sheep and beef and deer reduce across all GHG prices (Table 9). The largest decrease in production are observed for lamb meat and wool. Milk solid production increase at $25 tCO_2e^{-1} but decreases by 0.1% at $50 tCO_2e^{-1} and by 1.1% at $100 tCO_2e^{-1}. Production of remaining agricultural commodities, such as arable and horticultural products, increase with GHG prices because of the larger area in these crops. As noted in the data sources section (Section 2.3), timber production is not reported.

Table 15: Total agricultural production, ETS with farmer point of obligation and 95% free allocation

Commodities	Baseline (1,000 t)	Simulation results (% change)		
		$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Milk solid	1,554	0.01	–0.1	–1.1
Lamb	502	–0.5	–6	–22
Beef	424	–0.4	–3.7	–14
Wool	166	–0.5	–5.9	–20
Deer	47	–0.9	–2.8	–4.7
Wheat	1,024	0.03	0.3	0.5
Barley	853	0.03	0.3	0.5
Maize	1,422	0.03	0.3	0.5
Berries	100	0.04	0.3	0.9
Grapes	483	0.05	1	1.3
Pipfruit	42	0.05	0.2	0.8
Kiwifruit	79	0.04	0.3	0.9
Vegetables	1,463	0.04	0.7	0.9

Note: It was not possible to derive timber production from the FIF output and so timber output is not reported.

3.2 ETS with processor point of obligation and 95% free allocation

3.2.1 Land use

As with the previous scenario, the ETS with processor point of obligation leads to small impacts on land use area (Table 16) as processors only pay for (and pass onto farmers) the cost of 5% of biological GHG emissions. A small area of pastoral land does move into horticulture, arable, and forestry at all GHG prices. This policy mainly affects the deer and sheep and beef sectors. Deer has a comparatively high GHG emission factor (21 tCO_2e^{-1} per tonne of venison) and has no mitigation options available in the model. Hence, deer area decreases the most in relative terms (between –1.7% and –6% across GHG prices). At $100 tCO_2e^{-1}, the area of sheep and beef decreases by 0.4%. The dairy area increases slightly by about 0.07% at $25 tCO_2e^{-1}. However, as the GHG price increases the area in dairy decreases by up to 0.1%. Forestry area increases for all GHG prices as it generates revenue from payments for carbon sequestration. For instance, forestry area increases by about 0.2% (5,000 ha) at $25 $tCO2e^{-1}$ and by about 2% (44,000 ha) at $100 tCO_2e^{-1}. Arable and horticultural crops have lower GHG emissions and larger net revenues than pastoral land uses, and in this scenario GHG emissions from these sectors are not priced as there is no processor point of obligation. At the highest GHG price, the arable area increases by 0.8% (2,800 ha).

Table 16: Land use area, ETS with processor point of obligation and95% free allocation

Land uses	Baseline (1,000 ha)	Simulation results (% change)		
		$25 tCO_2e^{-1}	**$50 tCO_2e^{-1}**	**$100 tCO_2e^{-1}**
Arable	341	0.03	0.3	0.8
Fruits	38	0.05	0.2	0.8
Vegetables	37	0.08	0.6	1
Pipfruit	16	0.05	0.2	0.5
Viticulture	42	0.09	0.7	1
Forestry	2,223	0.2	0.6	2
Dairy	2,098	0.07	–0.03	–0.1
Sheep and beef	8,263	–0.04	–0.1	–0.4
Deer	214	–1.7	–3	–6

This scenario does not encourage the dairy sector to adopt any mitigation options even at the highest GHG price (Table 17). The sheep and beef sector plants woodlots on 3% of its land at $25 $tCO2e^{-1}$ and 15% of its land at $50 tCO_2e^{-1}. At $100 tCO_2e^{-1} woodlots are planted on approximately 36% of the area. This is due to the income generated from forest carbon sequestration.

Table 17: Land use area by management practices, ETS with processor point of obligation and 95% free allocation

Management practice	Simulation results (1,000 ha)		
	$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Dairy			
No mitigation	2,099	2,098	2,096
Output approach	0	0	0
Reduction in fertilizer use	0	0	0
Change in supplementary feed	0	0	0
Reduction in cow numbers and same milk production per cow	0	0	0
Once-a-day milking	0	0	0
Planting forestry	0	0	0
Sheep and beef			
No mitigation	8,034	6,998	5,294
Reduction in stocking rates	0	0	
Removal of breeding cows	2.6	2.8	4.5
Planting forestry	222	1,252	2,952

3.2.2 Net revenue

Net revenue from the agricultural and forestry sector decreases by up to 0.9% at the highest GHG price. These relatively small impacts on net revenue are due to processors only paying for (and passing onto farmers) the cost of 5% of biological GHG emissions. The reduction in net agricultural and forestry revenue differs to that of the previous scenario. In this scenario, pricing biological emissions at the processor level treats all livestock farmers who supply processors the same, regardless of their individual emissions levels. Thus, this policy fails to recognise the farmers who are reducing their emissions while keeping the same amount of production. Pricing emissions at the farm level, however, accounts for the emission levels at the individual farmer level and thus encourages the adoption of mitigation options. This leads to the difference in net revenue impacts between the two scenarios.

At the sectoral level, deer experiences the largest relative decrease in net revenue compared with the baseline (Table 18). Even at the lowest GHG price of $25 tCO_2e^{-1}, net revenue from deer decreases by about 3%. This is driven by the comparatively high GHG emission factor, and reduction in deer area (Table 16). Although sheep and beef farmers plant woodlots on some of their land area to mitigate their emissions and earn additional revenue from carbon sequestration payments, the overall net revenue from this sector decrease by 0.6% at $25 $tCO_2e^{-1}$and by 3.7% at $100 tCO_2e^{-1}. Net revenue from dairy decreases by about 0.6% at $25 tCO_2e^{-1} and by 2.4% at $100 tCO_2e^{-1}. Net revenues from forestry, arable, and horticultural crops increase as these sectors experience an increase in their land area and face no GHG emissions costs as only livestock emissions are priced at the processor level. Forestry has the largest net revenue gain because of carbon sequestration payments where net revenue increases by 0.3% ($3 million) at $25 tCO_2e^{-1}, and by 1.9% ($65 million) at $100 tCO_2e^{-1}.

Table 18: Net revenue, ETS with processor point of obligation and 95% free allocation

Land uses	Baseline ($ million)	Simulation results (% change)		
		$25 tCO_2e^{-1}	**$50 tCO_2e^{-1}**	**$100 tCO_2e^{-1}**
Arable	563	0.03	0.3	0.8
Fruits	278	0.06	0.2	0.8
Vegetables	442	0.09	0.8	1.1
Pipfruit	101	0.05	0.2	0.7
Viticulture	666	0.09	0.8	1.2
Forestry net revenue for baseline at $25 tCO_2e^{-1}	1,214	0.3	n.a	n.a.
Forestry net revenue for baseline at $50 tCO_2e^{-1}	1,941	n.a.	0.5	n.a.
Forestry net revenue for baseline at $100 tCO_2e^{-1}	3,403	n.a.	n.a.	1.9
Dairy	2,810	–0.6	–1	–2.4
Sheep and beef	2,695	–0.6	–1.1	–3.7
Deer	125	–2.6	–4.9	–9.7
Net revenue for baseline at $25 tCO_2e^{-1}	**8,891**	**–0.4**	**n.a.**	**n.a.**
Net revenue for baseline at $50 tCO_2e^{-1}	**9,626**	**n.a.**	**–0.5**	**n.a.**
Net revenue for baseline at $100 tCO_2e^{-1}	**11,083**	**n.a.**	**n.a.**	**–0.9**

Note: There are three 2020 baselines as there is a different baseline for each of the GHG prices as there is already a payment for the carbon sequestered by forestry; n.a. denotes where there are no values.

3.2.3 GHG emissions and carbon sequestration

At $25 tCO_2e^{-1} total emissions decrease by 0.3%, and at $50 tCO_2e^{-1} and $100 tCO_2e^{-1} total emissions decrease by 3% and 12%, respectively (Table 19). Net GHG emissions decrease between 5% and 91%. The larger net GHG emission reductions at higher GHG prices are mainly due to the increase in woodlots on sheep and beef farms. For example, at 100 $ tCO_2e^{-1} woodlots on sheep and beef land sequester about 5 million tCO_2e, which is about 15% of total carbon sequestration. Even at $25 tCO_2e^{-1}, forestry carbon sequestration increases by 2%. GHG emissions from dairy, sheep and beef, and deer are reduced at all GHG prices, except for dairy emissions at $25 tCO_2e^{-1}, which increase slightly because of the small increase in area. GHG emissions from arable and horticulture sectors increase along with land use area as their emissions are not priced in this scenario.

Table 19: GHG emissions and carbon sequestration, ETS with processor point of obligation and 95% free allocation

Land uses	**Baseline (1,000 tCO_2 e^{-1})**	**Simulation results (% change)**		
		$25 tCO_2e^{-1}	**$50 tCO_2e^{-1}**	**$100 tCO_2e^{-1}**
Arable	341	0.03	0.3	0.8
Fruits	10	0.06	0.2	0.8
Vegetables	14	0.09	0.8	1
Pipfruit	1	0.05	0.3	0.8
Viticulture	3	0.09	0.9	0.7
Dairy	15,825	0.01	–0.1	–0.9
Sheep and beef	24,043	–0.4	–5	–20
Deer	778	–2	–3	–4
Forestry	–29,232	2	11	20
Gross CO_2 emissions	**41,016**	**–0.3**	**–3**	**–12**
Total net GHG emissions	**11,784**	**–5**	**–37**	**–91**

Note: *negative value for forestry represents CO_2 sequestration levels. Forestry sequestration also includes carbon sequestration from planting woodlots on dairy and sheep and beef land.

The reductions in total CH_4 and N_2O emissions increase as GHG prices increase (Table 20 and Table 21). For example, at $25 tCO_2e^{-1}, CH_4 emissions reduce by 0.5% and N_2O emissions reduce by 0.4%. At $100 tCO_2e^{-1}, they both reduce by about 13%. The reduction in sheep and beef area and the adoption of mitigation options account for most of the reductions in total CH_4 and N_2O emissions. The increase in dairy area at $25 tCO_2e^{-1} (Table 16) increases its CH_4 and N_20 emissions. However, these emissions from dairy decrease at higher GHG prices.

Table 20: Total CH_4 emissions, ETS with processor point of obligation and 95% free allocation

Land uses	Baseline (1,000 t CH_4)	Simulation results (% change)		
		25 $ tCO_2^{-1}	50 $ tCO_2^{-1}	100 $ tCO_2^{-1}
Dairy	450	0.007	–0.06	–1
Sheep and beef	634	–0.8	–8	–21
Total CH_4 emissions	**1,085**	**–0.5**	**–4**	**–13**

Table 21: Total N_2O emissions, ETS with processor point of obligation and 95% free allocation

Land uses	Baseline (1,000 t N_2O)	Simulation results (% change)		
		$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Dairy	15	0.002	–0.3	–0.8
Sheep and beef	27	–0.7	–6	–21
Total N_2O emissions	**43**	**–0.4**	**–4**	**-13**

3.2.4 Agricultural production

Livestock farmers face lower output prices (as the cost of biological emissions is passed onto farmers through their product price) and this leads to a reduction in pastoral land area and a corresponding reduction in beef, lamb and deer meat, and wool production across all GHG prices (Table 22). At $25 tCO_2e^{-1}, the largest relative decrease in production is observed for deer meat. The increase in GHG prices further reduces the production of lamb, beef and deer meat, and wool. For instance, at $100 tCO_2e^{-1}, lamb production falls reduces by 22% and wool decreases by 20%. Milk solid output does not change at the lowest GHG price, but there are reductions up to 0.8% as GHG prices reach $100 tCO_2e^{-1}. The production of grains, fruits and vegetables increase with higher GHG prices due to increase in their area.

Table 22: Agricultural production, ETS with processor point of obligation and 95% free allocation

Commodities	Baseline (1,000 t)	Simulation results (% change)		
		$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Milk solid	1,554	0	-0.2	-0.8
Lamb	502	-0.4	-6	-22
Beef	424	-0.3	-4	-13
Wool	166	-0.4	-6	-20
Deer	47	-2	-3	-4
Wheat	1,024	0.03	0.3	0.8
Barley	853	0.03	0.3	0.8
Maize	1,422	0.03	0.3	0.8
Berries	100	0.07	0.2	0.8
Grapes	483	0.09	0.7	1.1
Pipfruit	42	0.05	0.2	0.6
Kiwifruit	79	0.07	0.2	0.8
Vegetables	1,463	0.09	0.5	0.9

Note: It was not possible to derive timber production from the FIF output and so timber output is not reported.

3.3 ETS with farmer point of obligation for agricultural emissions and decoupled 95% free allocation

3.3.1 Land use

Decoupling the 95% free allocation from current emissions leads to substantial impacts on the area in different land uses (Table 23). Because the free allocation is not tied to the current emissions, farmers face the full cost of their current biological emissions. There is a payment back to the sector for the 95% free allocation, but our modelling does not specify how this payment is returned to individual farmers. Instead, there is a lump sum transfer back to the agricultural sector as a whole. Therefore, there is not a direct signal to farmers of any reduced payment obligation.

The GHG emission prices reduce net revenue from high emitting pastoral land uses and as a result, some pastoral land shifts into forestry, arable, horticulture uses. For instance, a $25 tCO_2e^{-1} GHG price reduces sheep and beef area by about 4% (322,000 ha), dairy area by 2% (40,000 ha) and deer area by 16% (34,000 ha). The reduction in area is more pronounced as the GHG price increases. At the highest GHG price of $100 tCO_2e^{-1} the dairy area declines by about 17% while the sheep and beef area decreases by around 16%. The deer sector experiences the largest percentage decrease in area. At $100 tCO_2e^{-1}, the area in deer reduces by 77%. The large decline in deer area is the result of its high GHG emissions with respect to net revenue and the lack of mitigation options.

There is a large shift towards forestry plantations because of carbon sequestration payments. Forestry area increases by 17% (387,000 ha) at $25 tCO_2e^{-1} and by 80% (1.8 million ha) at $100 tCO_2e^{-1}. Arable and horticultural farms have lower GHG emissions and larger net revenue than pastoral land uses, and consequently their land use area increases. Combined arable and horticultural area increases by 9,400 ha at $25 tCO_2e^{-1}, by 20,000 ha at $50 tCO_2e^{-1}, and by 64,000 ha at $100 tCO_2e^{-1}.

Table 23: Land use area, ETS with farmer point of obligation and decoupled 95% free allocation

Land uses	Baseline (1,000 ha)	Simulation results (% change)		
		$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Arable	341	2	5	11
Fruits	38	1	3	13
Vegetables	37	2	4	20
Pipfruit	16	1	2	17
Viticulture	42	2.2	4.3	22
Forestry	2,223	17	34	80
Dairy	2,098	–2	–8.5	–17
Sheep and beef	8,263	–4	–6	–16
Deer	214	–16	–48	–77

The decoupling of the 95% free allocation encourages dairy and sheep and beef farmers to adopt GHG mitigation options. At \$25 tCO_2e^{-1}, dairy farmers adopt mitigation options on about 6% of their land area (Table 24) and at \$100 tCO_2e^{-1} mitigation options are adopted on 43% of the dairy land. At \$100 tCO_2e^{-1} there is a greater adoption of the output approach and the planting of woodlots. The planting of woodlots is encouraged by the payments for the sequestered carbon which is more profitable for many dairy farmers than not having any mitigation.

Planting woodlots is the main mitigation option adopted by sheep and beef farmers, followed by removing breeding cows at all GHG prices. At \$100 tCO_2e^{-1} approximately 78% of the sheep and beef area has woodlots planted on a portion of their land, which receives a carbon sequestration payment and reduces GHG emissions.

Table 24: Land use area by management practices, ETS with farmer point of obligation and decoupled 95% free allocation

	Simulation results (1,000 ha)		
Management practice	**\$25 tCO_2e^{-1}**	**\$50 tCO_2e^{-1}**	**\$100 tCO_2e^{-1}**
Dairy			
No mitigation	1,928	1,775	996
Output approach	36	44	112
Reduction in fertilizer use	6	9	21
Change in supplementary feed	39	35	34
Reduction in cow numbers and same milk production per cow	0	0	15
Once-a-day milking	19	18	17
Planting forestry	26	36	547
Sheep and beef			
No mitigation	6,773	4,096	1,405
Reduction in stocking rates	1	1	0
Removal of breeding cows	13	14	97
Planting forestry	1,154	3,657	5,438

3.3.2 Net revenue

The pastoral sectors experience marked reductions in total net revenue as pastoral farmers bear the full cost of their current biological emissions. Even at the lowest GHG price the net revenue for deer decreases by 28% (\$35 million), sheep and beef revenue decreases by 26% (\$701 million), and dairy revenue decreases by 14.5% (\$407 million) (Table 25). As GHG prices increase the negative impacts on net revenue increase non-linearly. At \$100 tCO_2e^{-1}, net revenue for dairy decreases by 59%, sheep and beef decreases by 73%, and deer decreases by 94%.

As pastoral land converts to lower emitting and more profitable forestry, arable, and horticultural uses, net revenues from these sectors increase for all GHG prices. Forestry has the largest increase in net revenue due to the increase in area and larger carbon sequestration payments. Even at the lowest carbon sequestration payments, forestry net revenue increases by 13%, and at \$100 tCO_2e^{-1}, they increase by 44%. However, once the decoupled 95% free allocation from current emissions is accounted for there is an increase in overall net agricultural revenue (Table 26). This is because the agricultural sector receives a credit for 95% of their historic emissions. At \$25 $tCO2e^{-1}$ this results in a small increase in net revenue (0.2%) which increases to about 18% at \$100 $tCO2e^{-1}$.

Table 25: Net revenue by land use sector, ETS with farmer point of obligation and decoupled 95% free allocation (Not accounting for 95% free allocation credit)

Land uses	Baseline (\$ millions)	Simulation results (% change)		
		\$25 tCO_2e^{-1}	\$50 tCO_2e^{-1}	\$100 tCO_2e^{-1}
Arable	563	0.6	-0.2	4
Fruits	278	1	5	13
Vegetables	442	2	5	18
Pipfruit	101	1	5	12
Viticulture	666	2	6	22
Forestry net revenue for baseline at \$25 tCO_2e^{-1}	1,211	13	n.a.	n.a.
Forestry net revenue for baseline at \$50 tCO_2e^{-1}	1,941	n.a.	21	n.a.
Forestry net revenue for baseline at \$100 tCO_2e^{-1}	3,403	n.a.	n.a.	44
Dairy	2,810	–15	–31	–59
Sheep and beef	2,695	–26	–44	–73
Deer	125	–28	–63	–94

Note: There are three 2020 baselines as there is a different baseline for each of the GHG prices as there is already a payment for the carbon sequestered by forestry; n.a. denotes where there are no values.

Table 26: Net revenue with credit for 95% free allocation, ETS with farmer point of obligation with decoupled 95% free allocation

GHG price	Baseline net revenue (\$ millions)	Scenario net revenue (\$ millions)	Credited 95% free allocation (\$ millions)	Scenario net revenue with credited allocation (\$ millions)	Change in net revenue (% change)
\$25 tCO_2e^{-1}	8,891	7,934	974	8,908	0.2%
\$50 tCO_2e^{-1}	9,626	8,001	1,948	9,949	3.4%
\$100 tCO_2e^{-1}	11,083	9,134	3,897	13,031	17.6%

3.3.3 GHG emissions and carbon sequestration

This scenario achieves large reductions in GHG emissions as farmers change land use and adopt mitigation options in response to facing the full price of their biological emissions (i.e. decoupling the 95% free allocation from their current emissions). Gross GHG emission fall between 6% and 35% depending on the GHG price (Table 27). Carbon sequestration is greater than GHG emissions at \$50 tCO_2e^{-1} and \$100 tCO_2e^{-1}. The increase in carbon sequestration from forestry results from the pastoral land that converts to forestry. Carbon sequestration increases by 22% at \$25 tCO_2e^{-1} and by 99% at \$100 tCO_2e^{-1}. These increases come from new forestry plantations and woodlots on sheep and beef and dairy farms. Sheep and beef land have the largest reduction in GHG emissions (up to 40%) among pastoral land uses followed by dairy (up to 28%) for all GHG prices. While the largest percent decrease is for deer, the smaller baseline emissions means the actual reduction in GHG emissions is smaller than the other livestock sectors. The increase in arable and horticultural area also leads to an increase in emissions in these sectors.

Table 27: Total GHG emissions and carbon sequestration, ETS with farmer point of obligation and decoupled 95% free allocation

Land uses	Baseline (1,000 tCO_2e^{-1})	Simulation results (% change)		
		\$25 tCO_2e^{-1}	\$50 tCO_2e^{-1}	\$100 tCO_2e^{-1}
Arable	341	2	3	11
Fruits	10	1	5	11
Vegetables	14	2	6	18
Pipfruit	1	0.9	4	8
Viticulture	3	2	6.4	22
Dairy	15,825	-2	-10	-28
Sheep and beef	24,043	-8	-23	-40
Deer	778	-20	-52	-74
Forestry	-29,232	22	52	99
Gross CO_2 emissions	**41,016**	**-6**	**-18**	**-35**
Total net GHG emissions	**11,784**	**-77**	**-192**	**-369**

Note: *negative value for forestry represents CO_2 sequestration levels. Forestry sequestration also includes carbon sequestration from planting woodlots on dairy and sheep and beef land.

The reductions in dairy and sheep and beef area reduces their CH_4 and N_2O emissions (Table 28 and Table 29). Total CH_4 and N_2O emissions both fall by about 35%. The sheep and beef sector have the largest reduction in these emissions, as it also has the largest reduction in land area and adopts mitigation options at all GHG prices.

Table 28: Total CH_4 emissions, ETS with farmer point of obligation and decoupled 95% free allocation

Land uses	Baseline (1,000 t CH_4)	Simulation results (% change)		
		$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Dairy	450	–2	–10	–29
Sheep and beef	634	–11	–19	–39
Total CH4 emissions	**1,085**	**–7**	**–16**	**–35**

Table 29: Total N_2O emissions, ETS with farmer point of obligation and decoupled 95% free allocation

Land uses	Baseline (1,000 t N_2O)	Simulation results (% change)		
		$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Dairy	15	–2	–11	–25
Sheep and beef	27	–10	–29	–41
Total N2O emissions	**43**	**–7**	**–20**	**–35**

3.3.4 Agricultural production

The production of all pastoral outputs decrease as land shifts out of pastoral uses (Table 30). The largest relative decrease in production is observed for deer meat at all GHG prices and is due to reduced area of deer. Milk solid production also decreases by 3% and 23%, respectively, for GHG prices of $25 tCO_2e^{-1} and $100 tCO_2e^{-1}. The production of the other agricultural commodities increases due to increases in their area. With the increase of GHG prices, production of livestock commodities further reduces, while production of horticulture and arable increases.

Table 30: Total agricultural production, ETS with farmer point of obligation and decoupled 95% free allocation

Commodities	Baseline (1,000 t)	Simulation results (% change)		
		$25 tCO_2e^{-1}	$50 tCO_2e^{-1}	$100 tCO_2e^{-1}
Milk solid	1,554	–3	–10	–23
Lamb	502	–9	–31	–25
Beef	424	–7	–21	–34
Wool	166	–8	–30	–24
Deer	47	–20	–53	–73
Wheat	1,024	2	3	11
Barley	853	2	3	11
Maize	1,422	2	3	11
Berries	100	1	5	18
Grapes	483	2	6	24
Pipfruit	42	0.9	4	16
Kiwifruit	79	1	5	18
Vegetables	1,463	2	5	22

Note: It was not possible to derive timber production from the FIF output and so timber output is not reported.

3.4 ETS with farmer point of obligation, technological innovations, and decoupled 95% free allocation

3.4.1 Land use

Technological innovations reduce the negative impact on pastoral farming area from pricing agricultural biological emissions (Table 31). Under this scenario, dairy area decreases by 1% at $25 tCO_2e^{-1} GHG price which is lower than in the same scenario without technological innovations (–2%). The smaller reduction in dairy area in turn leads to smaller increases in forestry, arable, and horticultural area. For instance, forestry area increases by about 16% (362,000 ha) and aggregated arable and horticulture area by just under 2% (8,700 ha) at $25 tCO_2e^{-1}, whereas in the same scenario without technological innovations forestry area increases by 17% (380,000 ha) while aggregated arable and horticulture area increases by just over 2% (9,400 ha). The area in sheep and beef and deer decrease at the same level as the previous scenario because technological innovations are not available for these sectors.

Table 31: Land use area, ETS with farmer point of obligation, technological innovations and decoupled 95% free allocation

Land uses	Baseline (1,000 ha)	Simulation results (% change)
Arable	341	2
Fruits	38	1
Vegetables	37	2
Pipfruit	16	0.7
Viticulture	42	2
Forestry	2,223	16
Dairy	2,098	–1
Sheep and beef	8,263	–4
Deer	214	–16

Dairy adopts mitigation options and technological innovations on about 61% of its land (Table 32). Of the dairy area, 60% (1.22 million ha) adopts the new technologies where most (about 59% or 1.21 million ha) adopts the option to reduce cow numbers (where the cows have higher milk production). The reduction in cow numbers option is preferred for most farms as it more cheaply mitigates the costs of current GHG emissions. Only 0.3% of the dairy area used nitrification inhibitors due to its relatively high cost. Nitrification inhibitors can increase milk solid production and revenues while reducing emissions but at a higher cost (see Table 54). For most dairy land the cost of nitrification inhibitors ($250 ha^{-1}) outweigh its benefit. For the same scenarios without technological innovations, the output approach and planting woodlots were adopted on about 2% (39,000 ha) of total dairy area. These mitigation options are still adopted in this scenario, but to a lesser extent, because they can lower the cost of GHG reductions in some dairy systems and regions better than other mitigation options and technological innovations.

The mitigation adoption for the sheep and beef sector remains the same as the previous scenario where the main mitigation option adopted is planting woodlots.

Table 32: Land use area by management practices, ETS with farmer point of obligation, technological innovations and decoupled 95% free allocation

Management practice	Simulation results (1,000 ha)
Dairy	
No mitigation	808
Output approach	24
Reduction in fertilizer use	0
Change in supplementary feed	0
Reduction in cow numbers and same milk production per cow	0
Once-a-day milking	0
Planting forestry	15
Reduction in cow numbers and increase in milk production per cow	1,215
Nitrification inhibitors	7
Sheep and beef	
No mitigation	6,779
Reduction in stocking rates	1.1
Removal of breeding cows	13
Planting forestry	1,158

3.4.2 Net revenue

Having technological innovations almost halves the negative impact of GHG emission pricing on dairy net revenue (Table 33). At $25 tCO_2e^{-1} GHG price dairy net revenue reduces by 8% ($222 million) compared to the baseline. The sheep and beef sector faces the largest reduction in net revenue (-26% or $697 million) from the baseline while net revenue from the deer sector falls by 28% ($35 million). These decreases in net revenue reductions for these sectors are the same as without technological innovations. Net revenue from the forestry, arable and horticultural sectors also increase. However, these gains are smaller than without technological innovations as less dairy land shifts into these land uses. The net revenue from forestry increases by 12% ($145 million) while the aggregated net revenue from horticulture and arable increases by 1% ($21 million).

As with the same scenario without technological innovations, decoupling the 95% free allocation from current emissions results in an increase in overall net agricultural revenue as the agricultural sector receives a credit for 95% of their historic emissions. However, the increase in net agricultural revenue is higher with technological innovations as the availability of new mitigation technologies reduces the cost of current biological emissions. At $25 $tCO2e^{-1}$ net agricultural revenue increases by 2%.

Table 33: Net revenue by land use sector, ETS with farmer point of obligation, technological innovations and decoupled 95% free allocation

Land uses	Baseline, $ millions	Simulation results, % change
Arable	563	0.4
Fruits	278	0.9
Vegetables	442	1
Pipfruit	101	0.5
Viticulture	666	2
Forestry net revenue for baseline at $25 tCO_2e^{-1}$	1,211	12
Dairy	2,810	–8
Sheep and beef	2,695	–26
Deer	125	–28

Note: we use the 2020 baseline for $25 tCO_2e^{-1}.

Table 34: Net revenue with credit for 95% free allocation, ETS with farmer point of obligation, technological innovations and decoupled 95% free allocation

GHG price	Baseline total net revenue ($ millions)	Scenario net revenue ($ millions)	Credited 95% free allocation ($ millions)	Scenario total net revenue with credited allocation ($ millions)	Change in total net revenue (% change)
$25 tCO_2e^{-1}	8,891	8,102	974	9,076	2

3.4.3 GHG emissions and carbon sequestration

The availability of technological innovations decreases current biological emissions from agricultural land uses by 8% (Table 35). Net GHG emissions also decrease by 78%. GHG emissions from dairy decreases by about 8% with cow numbers being reduced on majority of the area and decrease in land use area (see Table 31 and Table 32). GHG emissions from the sheep and beef sector also decrease by 8% and the deer sector by 20%. GHG emissions from arable and horticulture increase by 2%. The carbon sequestered by forestry also increases by 20% (5.9 million tCO_2) because of the increase in forestry area and planting of woodlots on dairy and sheep and beef farms.

Table 35: GHG emissions and CO_2 sequestration, ETS with farmer point of obligation, technological innovations and decoupled 95% free allocation

Land use	Baseline (1,000 tCO_2)	Simulation results (% change)
Arable	341	2
Fruits	10	1
Vegetables	14	2
Pipfruit	1	0.4
Viticulture	3	3
Dairy	15,825	–8
Sheep and beef	24,043	–8
Deer	778	–20
Forestry	–29,232	20
Gross CO_2 emissions	**41,016**	**–8**
Total net GHG emissions	**11,784**	**–78**

Note: *negative value for forestry represents CO_2 sequestration levels. Forestry sequestration also includes CO_2 sequestration from the establishment of farm forestry practice on dairy and sheep and beef farms.

Adoption of technological innovations and decrease land area reduces CH_4 and N_2O emissions from dairy beyond the reductions achieved without technological innovations (Table 36 and

Table 37). The decrease in sheep and beef GHG emissions is the same as there are no technological innovations currently available to this sector. Total CH_4 and N_2O emissions from aggregated dairy and sheep and beef emissions reduce by 10% and 9%, respectively.

Table 36: Total CH_4 emissions, ETS with farmer point of obligation, technological innovations and decoupled 95% free allocation

Land uses	Baseline (1,000 t CH_4)	Simulation results (% change)
Dairy	450	–8
Sheep and beef	634	–11
Total CH4 emissions	**1,085**	**–10**

Table 37: Total N_2O emissions, ETS with farmer point of obligation, technological innovations and decoupled 95% free allocation

Land uses	Baseline (1,000 t N_2O)	Simulation results (% change)
Dairy	15	–7
Sheep and beef	27	–10
Total N2O emissions	**43**	**–9**

3.4.4 Agricultural production

The production of all livestock outputs reduces because pastoral area decreases (Table 38). Overall milk solid production decreases by nearly as much as without technological innovations. This is because the reduction in cow numbers in this scenario has a similar effect as the decrease in dairy area with no technological innovations. Adoption of nitrification inhibitors can increase milk solid output; however, this technology is only adopted on a small area (see Table 32) due to its high costs (see Table 54). Production of remaining simulated agricultural commodities increases due to increase in their area.

Table 38: Agricultural production, ETS with farmer point of obligation, technological innovations and decoupled 95% free allocation

Commodities	Baseline (1,000 t)	Simulation results (% change)
Milk solid	1,554	–3
Lamb	502	–9
Beef	424	–7
Wool	166	–8
Deer	47	–20
Wheat	1,024	2
Barley	853	2
Maize	1,422	2
Berries	100	1
Grapes	483	2
Pipfruit	42	0.7
Kiwifruit	79	1
Vegetables	1,463	2

Note: It was not possible to derive timber production from the FIF output and so timber output is not reported.

3.5 Farm-level GHG emissions reduction targets

3.5.1 Land use

Imposing a GHG emission reduction target of 6% below baseline biological emission levels on all livestock sectors reduces the area in pastoral land uses (Table 39). To meet the GHG reduction target pastoral land moves to forestry, arable, and horticulture. The area in sheep and beef production decreases by 4% (331,000 ha), dairy decreases by just under 2% (32,000 ha), and deer decreases by 16% (34,000 ha). There relatively large decrease in deer area results from its high GHG emissions and lack of mitigation options. Forestry has the largest increase in area (17% or 386,000 ha) as it generates revenue from the carbon it sequesters. Arable and horticulture crops have lower GHG emissions and larger net revenues than pastoral land uses, thus they experience an increase in land use area. Combined arable and horticulture area increases by just under 2% (7,500 ha). The reduction in dairy area is slightly less than at a \$25 tCO_2e^{-1} GHG price with farmer point of obligation and decoupled 95% free allocation. More profitable but higher GHG emitting land uses are less affected in this scenario as biological emissions are not priced.

Table 39: Land use area, Farm-level GHG emissions reduction targets

Land uses	Baseline (1,000 ha)	Simulation results (% change)
Arable	341	2
Fruits	38	1
Vegetables	37	2
Pipfruit	16	1
Viticulture	42	2
Forestry	2,223	17
Dairy	2,098	–2
Sheep and beef	8,263	–4
Deer	214	–16

Dairy adopts mitigation options on about 7% of the land area to meet the GHG reduction target. The main mitigation options adopted are the output approach, change in supplementary feed, and planting woodlots (Table 40). Sheep and beef farmers predominantly plant woodlots (on 16% of their land), which is larger than at a \$25 tCO_2e^{-1} GHG price with farmer point of obligation and decoupled 95% free allocation.

Table 40: Land use area by management practices, Farm-level GHG emissions reduction targets

Management practice	Simulation results (1,000 ha)
Dairy	
No mitigation	1,913
Output approach	34
Reduction in fertilizer use	32
Change in supplementary feed	39
Reduction in cow numbers and same milk production per cow	0
Once-a-day milking	20
Planting forestry	26
Sheep and beef	
No mitigation	6,687
Reduction in stocking rates	0.8
Removal of breeding cows	13
Planting forestry	1,232

3.5.2 Net revenue

The GHG emission reduction target leads to a small reduction in net revenue (0.05%). In this scenario, farmers can adopt mitigation options or change land uses without paying a price on their biological emissions. Deer farmers face the largest relative decrease in net revenue (16%) among pastoral land uses (Table 41) because of the lack of mitigation options. Net revenue from the sheep and beef sector decreases by 5% ($141 million) while net revenue from the dairy sector decreases by just under 2% ($43 million). Net revenue from forestry, arable and horticultural sectors increase because these land uses have substantially lower GHG emissions and means some pastoral land shifts into these uses to meet the GHG emission target levels. The forestry sector has the largest relative increase in net revenue (13%) because of carbon sequestration payments and the larger area now in forestry.

Table 41: Total net revenue, Farm-level GHG emissions reduction targets

Land uses	Baseline ($ millions)	Simulation results (% change)
Arable	563	1
Fruits	278	1
Vegetables	442	2
Pipfruit	101	1
Viticulture	666	2
Forestry net revenue for baseline at $25 tCO_2e^{-1}$	1,211	13
Dairy	2,810	–0.9
Sheep and beef	2,695	-5
Deer	125	-16
Total net revenue for baseline at $25 tCO_2e^{-1}	**8,891**	**-0.05**

Note: we use the 2020 baseline for $25 tCO_2e^{-1}.

3.5.3 GHG emissions and carbon sequestration

The GHG emissions target was 6% of baseline emissions. Meeting this target resulted in a reduction in the net GHG emissions of 73% (Table 42). Forestry carbon sequestration increased by 23% and includes carbon sequestration from forestry plantations and from woodlots on dairy and sheep and beef land. The largest relative reduction of 20% in GHG emissions was for deer. Emissions from the sheep and beef sector decreased by just over 8% (about 2 million tCO_2e^{-1}) due to land use change and the adoption of mitigation options. GHG emissions from dairy decrease by about 1% (280,000 tCO_2e^{-1}) while arable and horticultural crops emissions increase by just over 1% (about 6,000 tCO_2e^{-1}).

Table 42: Total GHG emissions and carbon sequestration, Farm-level GHG emissions reduction targets

Land uses	Baseline (1,000 tCO_2 e^{-1})	Simulation results (% change)
Arable	341	1
Fruits	10	1
Vegetables	14	2
Pipfruit	1	1
Viticulture	3	2
Dairy	15,825	–2
Sheep and beef	24,043	–8
Deer	778	–20
Forestry	–29,232	23
Gross CO2 emissions	**41,016**	**–6**
Total net GHG emissions	**11,784**	**–73**

Note: *negative value for forestry represents CO_2 sequestration levels. Forestry sequestration also includes carbon sequestration from planting woodlots dairy and sheep and beef land.

The decrease in dairy and sheep and beef area and the adoption of mitigation options reduces their biological emissions (Table 43 and Table 44). Total CH_4 and N_2O emissions are about 6% and 5% lower than in the baseline, respectively. Sheep and beef has the largest reduction in biological emissions, as it also has the largest decrease in land area and a larger area adopted mitigation options.

Table 43: Total CH_4 emissions, Farm-level GHG emissions reduction targets

Land uses	Baseline (1,000 t CH_4)	Simulation results (% change)
Dairy	450	–2
Sheep and beef	634	–8
Total CH_4 emissions	**1,085**	**–6**

Table 44: Total N_2O emissions, Farm-level GHG emissions reduction targets

Land uses	Baseline (1,000 t N_2O)	Simulation results (% change)
Dairy	15	–1
Sheep and beef	27	–7
Total N_2O emissions	**43**	**–5**

3.5.4 Agricultural production

The production of milk solids, beef, lamb and deer meat and wool decrease because the area in pastoral land uses decreases (Table 45). The largest relative reduction for production is observed for deer meat (–21%). Meat and wool outputs are reduced as sheep and beef farmers adopt mitigation options that reduce production or land moves out of pastoral production. Milk solid production decreases by about 2% while the output of arable and horticultural products increases.

Table 45: Total agricultural production, Farm-level GHG emissions reduction targets

Commodities	Baseline (1,000 t)	Simulation results (% change)
Milk solid	1,554	–2
Lamb	502	–9
Beef	424	–8
Wool	166	–9
Deer	47	–21
Wheat	1,024	2
Barley	853	2
Maize	1,422	2
Berries	100	1
Grapes	483	3
Pipfruit	42	0.8
Kiwifruit	79	1
Vegetables	1,463	2

Note: It was not possible to derive timber production from the FIF output and so timber output is not reported.

4 Conclusions

This report assessed the impacts of climate change mitigation policies on agricultural and forestry sectors, particularly on biological GHG emissions and carbon sequestration, land use, net revenue, and agricultural production. We analysed five scenarios aimed to reduce biological GHG emissions (methane and nitrous oxide) from agriculture. Three scenarios are assessed for three GHG prices (\$25 tCO_2e^{-1}, \$50 tCO_2e^{-1} and \$100 tCO_2e^{-1}) while the other two scenarios use a GHG price of \$25 tCO_2e^{-1}. We used the NZFARM model to analyse the impacts of these policy scenarios.

Results from this study show that pricing current biological emission with a 95% free allocation slightly reduces total net revenue (up to –0.5%) but is not very effective at reducing total GHG emissions at lower GHG prices (i.e. \$25 tCO_2e^{-1}). Even at higher GHG prices there is only a small reduction in GHG emissions. This is because, with a 95% free allocation on current emissions, the GHG price signal not large enough to stimulate a response from farmers. While small there is some movement of pastoral land to forestry with smaller areas moving to arable and horticulture uses. Sheep and beef adopt some mitigation options, such as removing breeding cows and planting forestry. Dairy, however, does not adopt any mitigations even at the highest GHG price. Although the difference in point of obligation for pricing emissions does not affect the impact on biological emissions it affects the impact on net revenues. With the processor point of obligation, all livestock farmers who supply processors are treated the same, regardless of their individual emissions levels. Thus, the processor point of obligation fails to recognise the farmers who are reducing their emissions while maintaining their production levels. With the farm point of obligation, however, emission at the individual farmer level are considered which encourages the adoption of mitigation options.

Decoupling the 95% free allocation from current biological emissions means that farmers face the full price on all current biological GHG emissions. Subsequently, there is a net payment back to the sector for the 95% free allocation based on their historical emissions. However, our modelling does not specify how this payment is returned to individual farmers and instead, there is a lump sum transfer back to the agricultural sector. Therefore, farmers do not get a direct signal of any reduced payment obligation. Decoupling the 95% free allocation from current biological emissions leads to greater reductions in total GHG emissions. These GHG emissions come with large changes in land use area where pastoral land shifts to forestry, arable, and horticultural uses. It also encourages dairy and sheep and beef farms to adopt mitigation options. As a result, there are large changes in net revenue for the livestock sectors. However, decoupling the 95% free allocation from current emissions resulted in an increase in overall net agricultural revenue as the agricultural sector receives a credit for 95% of their historic emissions. It makes the decoupled 95% free allocation scenarios economically more favourable for reducing GHG emissions in the agricultural sector. As new technologies that reduce GHG emissions while improving/maintaining agricultural productivity become available, the negative impact on the area in pastoral land uses and net revenue can be reduced. It should be noted, however, the modelled results might differ from reality due to different farmer preferences for adopting different mitigation options. Technologies might not be adopted immediately as farmers often require time to learn about or to gain confidence in new practices or technologies. This may mean that even if a technology is profitable it may take time or may not even be taken up by different farmers. Including rate and scope of technology adoption and diffusion into the model could lead to more realistic outcomes (Morgan & Daigneault 2015).

A GHG emission reduction target of 6% below baseline biological emission levels imposed on all agricultural land uses (excluding forestry) achieves the same emissions reductions as the \$25 tCO_2e^{-1} GHG price with farmer point of obligation and decoupled 95% free allocation, but at lower cost to farmers. Because emissions are not priced, farmers have more flexibility to adopt mitigation options or change their land use to meet the reduction target. To implement this policy, however, institutional mechanisms need to be developed that can estimate/measure, monitor and report the GHG emission levels from different land uses. Enforcement processes are also needed. All these will increase the transaction costs of the policy.

There are some nuances that our modelling does not account for. For instance, we assume the policy scenarios are immediately implemented when in reality land use changes and adoption of mitigation options will occur over time. Dynamic modelling could assess this transition. Our modelling does not track what land uses change to other land uses as land use is not tracked at the individual farm level, and the economy-wide effects of the policies have not been included in this analysis. Additional modelling would be needed to assess economy-wide impacts. Future analysis could also assess the impacts on other environmental parameters such as sediment, nutrient leaching, and water yield.

5 References

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Appendix 1 – Data on mitigation options

Table 46, Table 47 and Table 48 provide information obtained from DairyNZ on GHG emissions, net revenue, and milk solid production for different dairy 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 46: Summary statistics of relative change (%) in greenhouse gas emissions for dairy under different mitigation options, per hectare

Mitigation option	Mean	Std dev.	90th percentile	70th percentile	30th percentile	10th percentile
No mitigation, kg CO_2e ha^{-1}	**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 fertilizer 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 fertilizer 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_2e ha^{-1}	**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

Source: DairyNZ Economic Group (2017).

Table 47: Summary statistics of relative change (%) in net revenue of dairy under different mitigation options, per hectare

Mitigation option	Mean	Std dev.	90th percentile	70th percentile	30th percentile	10th percentile
No mitigation, $ ha^{-1}	**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 fertilizer 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 fertilizer 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

Source: DairyNZ Economic Group (2017).

Table 48: Summary statistics of relative change (%) in milk solid production at dairy under different mitigation options, per hectare

Mitigation option	Mean	Std dev.	90th percentile	70th percentile	30th percentile	10th percentile
No mitigation, kg ha^{-1}	**977**	**259**	**1,340**	**1,028**	**830**	**657**
Output approach reducing GHG emissions, % change from no mitigation						
5% reduction	–2.1	–0.9	–2.2	–2.6	–3.0	–2.2
10% reduction	–5.0	–2.8	–5.3	–4.9	-6.6	–5.4
15% reduction	–8.3	–5.4	–8.3	–8.1	–10.0	-8.3
20% reduction	–11.4	–8.9	–11.7	–10.5	–13.5	-11.1
Reduction in fertilizer use, % change from no mitigation						
25% reduction	–3.0	–3.3	–3.2	–2.4	–2.8	-2.8
50% reduction	–6.1	–5.9	–5.6	–4.5	–6.3	-4.7
75% reduction	–9.2	–9.4	–8.4	–6.6	-9.3	-7.6
No fertilizer use	-*12.4	–13.0	–12.2	–8.6	–12.3	–12.3
Change in supplementary feed, % change from no mitigation						
Switch 50% of supplementary feed to low protein feed	–0.1	0.5	0.1	–0.1	–0.3	-0.2
Switch 100% to low protein feed	–0.1	0.6	0.0	–0.4	-0.7	–0.3
Reduce imported high protein volumes by 50% and reduce stocking rate	-3.5	–4.0	–7.8	–1.9	–3.3	–1.9
Remove all imported high protein volumes and reduce stocking rate	–7.5	–7.6	–13.4	–5.8	–6.9	-4.2
Reduction in cow numbers and same milk production per cow, % change from no mitigation						
5% reduction	–5.1	–4.8	–5.1	–5.1	–5.1	–5.4
10% reduction	–10.0	–9.9	–10.0	–10.2	–10.3	–10.2
15% reduction	–14.6	–14.8	–14.9	–14.8	–15.1	–14.9
20% reduction	–19.0	–19.2	–19.5	–19.1	-19.7	-19.2
Once-a-day milking, % change from no mitigation						
Half a season	–2.0	1.9	0.0	0.0	–3.6	–3.9
Entire season	–2.7	2.9	0.0	–2.0	–4.1	–5.3
Planting forestry on milking platform, % change from no mitigation						
5% forestry	–0.4	0.7	–0.9	0.2	0.2	–1.7
10% forestry	–0.8	1.1	–1.7	–0.2	–0.5	–3.0
15% forestry	–2.7	–3.3	–8.0	0.2	0.2	–4.5
20% forestry	–0.8	2.5	–3.0	1.1	–0.4	–5.6

Source: DairyNZ Economic Group (2017).

Table 49 shows the mean net revenue and GHG emission values for sheep and 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 net revenue, stocking rate (sheep, beef cattle, deer and goats) and production (wool, lamb, beef and venison) from different sheep and beef systems were obtained from the sheep and beef farm survey of Beef + Lamb New Zealand. Based on this survey, we considered six systems/types for sheep and beef farms. The relative effect of sheep and beef farm mitigation options was obtained from Reisinger et al. (2017).

Table 49: Relative change (%) in net revenue and greenhouse gas emissions of sheep and beef under different mitigation options, per hectare

Mitigation option		**Impact**	
	Farm system	**Profit (%)**	**GHG emission (%)**
No mitigation*	NI hill	$310 ha^{-1}	3.49 t ha^{-1}
	NI intensive	$402 ha^{-1}	4.11 t ha^{-1}
	SI hill	$90 ha^{-1}	0.92 t ha^{-1}
	SI intensive	$549 ha^{-1}	3.59 t ha^{-1}
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 net revenue and greenhouse gas emissions for the 'No mitigation option' are averages across regions.

Appendix 2 – Data on technological innovations

Table 50, Table 51, Table 52Table 53 show the change in GHG emissions, net revenue and milk solids, respectively for dairy cow number reduction and increase in milk production per cow practice. Information on this practice differs by dairy type and regions.

Table 50. Summary statistics of relative change (%) in greenhouse gas emissions for dairy reduction in cow numbers and increase in milk production per cow, per hectare

Mitigation option	Mean	Std dev.	90th percentile	70th percentile	30th percentile	10th percentile
No mitigation, kg CO_2e ha^{-1}	**9,220**	**1,666**	**11,519**	**10,238**	**8,122**	**7,325**
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 (2018).

Table 51: Summary statistics of relative change (%) in net revenue of dairy under reduction in cow numbers and increase in milk production per cow, per hectare

Mitigation option	Mean	Std dev.	90th percentile	70th percentile	30th percentile	10th percentile
No mitigation, \$ ha^{-1}	**1,599**	**768**	**2,515**	**1,915**	**1,216**	**688**
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 (2018).

Table 52: Summary statistics of relative change (%) in milk solid production at dairy under reduction in cow numbers and increase in milk production per cow, per farm

Mitigation option	Mean	Std dev.	90th percentile	70th percentile	30th percentile	10th percentile
No mitigation, kg MS $farm^{-1}$	**189,475**	**96,000**	**308,395**	**234,646**	**118,602**	**94,651**
Reduction in cow numbers and increase in milk production per cow, % change from no mitigation						
5%	–2.6	–2.4	–2.6	–2.5	–2.6	–2.7
10%	–5.0	–4.9	–4.9	–5.0	–5.0	–5.1
15%	–7.3	–7.2	–7.4	–7.4	–7.3	–7.4
20%	–9.5	–9.4	–9.6	–9.6	–9.6	–9.6

Source: DairyNZ Economic Group (2018).

Table 53: Summary statistics of relative change (%) in milk solid production at dairy under reduction in cow numbers and increase in milk production per cow, per cow

Mitigation option	Mean	Std dev.	90th percentile	70th percentile	30th percentile	10th percentile
No mitigation, kg MS cow^{-1}	**390**	**44**	**459**	**412**	**358**	**342**
Reduction in cow numbers and increase in milk production per cow, % change from no mitigation						
5%	2.7	3.1	2.8	2.7	2.8	2.7
10%	5.6	6.4	5.8	5.7	5.6	5.6
15%	8.5	9.4	8.9	8.5	8.6	8.6
20%	11.7	13.7	12.3	11.8	11.8	11.7

Source: DairyNZ Economic Group (2018).

Table 54 shows change in milk solid production and N2O emissions and costs in the South and North Island of nitrification inhibitors technology. We distributed this information by South and North Island dairy farms.

Table 54: Milk solid output, costs and N2O emissions of nitrification inhibitors at dairy, per hectare

	Milk solid change, %	N2O emission change, %	Nitrification inhibitors cost, $ ha^{-1}
Nitrification inhibitors South Island	1.4	-60	250
Nitrification inhibitors North Island	0.9	-60	250

Source: Carey et al. (2012); Reisenger & Clark (2016).