Land-use Change as a Mitigation Option for Climate Change

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Summary Haiku

To meet our targets
Help horticulture to grow
Let forests respond.

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Executive Summary

Introduction

This report explores how changes in the way land is used can mitigate greenhouse gas (GHG) emissions. It focuses on cost-effective land-use responses that could be implemented by landowners but it does not recommend who should bear the costs of those changes. The scenarios presented were developed by the Biological Emissions Reference Group with input from the modelling team.

The main project objective is to predict the likely extent and nature of land-use change as part of a cost-effective response to land-sector mitigation targets and the potential economic, and social impacts of these changes.[1] We also explore:

- how those land-use changes, and the intensity of effort required to achieve them, vary with the timing and stringency of targets and with different assumptions about new land uses and technology; and
- national impacts on gross domestic product (GDP), production of key export commodities, and employment.

We use three models: Motu's Land Use in Rural New Zealand model (LURNZ), Manaaki Whenua – Landcare Research's New Zealand Forestry and Agricultural Regional Model (NZFARM), and Infometrics' Energy Substitution, Social Accounting Matrix (ESSAM). The land-use models simulate how land use might change to achieve a given emission target in the lowest cost way. Essentially both land-use models take a common reference scenario for land-use patterns in future years and then shift land uses from high emission uses toward lower emission uses until the emission target is met. Each model takes a different approach (statistical versus optimisation) to identify the combination of land-use changes that is likely to achieve this at lowest cost. In both models this is done through modelling the effect of an implicit price for emissions on the economic returns to landowners for different products. We consider a lower level of pressure to reduce biological agricultural emissions than to encourage additional forestry to reflect the current Government's intentions.[2] This allows for the use of various policy levers to achieve changes in land use and does not assume that agriculture will be included in the Emissions Trading Scheme (ETS).

We consider the impact of on-farm mitigation only in terms of how an assumed level might affect the land-use changes needed. The potential for mitigation via changing farming practices but not land use is covered by a separate project. For new technologies (we examine

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[1] By 'land-sector' we mean the combination of agriculture, horticulture, arable, forestry, scrub and native forest.

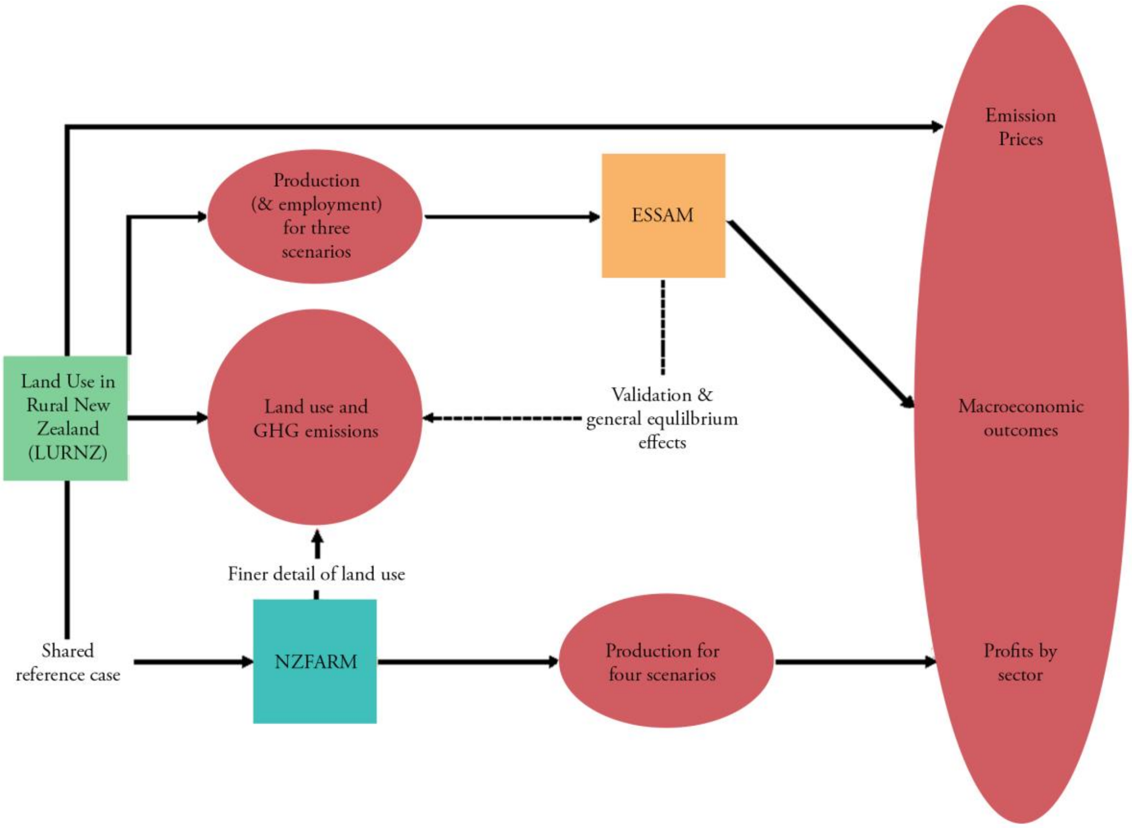
[2] In LURNZ we assume that the implicit price applied to biological emissions from agriculture is only 5% of the ETS price with current metrics from 2020, rising 3 percentage points annually until 2030; 5 percentage points annually thereafter.

horticultural expansion and a methane vaccine – or equivalent other mitigation technology such as an inhibitor or significant change in farm practice) to be viable, New Zealand will require policies that will facilitate, encourage, or require their uptake.

Modelled scenarios

In this work we utilise a mix of literature review, modelling, and qualitative approaches. We combine three economic models because no one model can produce all desired outputs, and because using different model structures and assumptions provides a robustness check on results. Land-use change simulations are created using the two main economic land-use models available in New Zealand – Motu's Land Use in Rural New Zealand model (LURNZ) and Manaaki Whenua Landcare Research's New Zealand Forestry and Agricultural Regional Model (NZFARM). The models share a common base land-use map for 2012 and simulated reference case maps for 2030 and 2050. As each model is underpinned by different algorithms, characteristics, and assumptions, it is not possible to model the exact same scenarios for both. However, the scenarios are very close in nature and can therefore be compared usefully.

ES 1 Combining three economic models to simulate and compare outcomes



The three mitigation targets modelled in this study are:

- Reference (no additional ambition for land sector – existing ETS only);
- Low-ambition (LA) scenario (reduction in net land-sector emissions relative to reference case, by an amount of 15% of 2005 gross biological emissions from agriculture, by 2030 – 25% by 2050);[3] and
- High-ambition (HA) scenario (reduction in net land-sector emissions relative to reference case, by an amount of 30% of 2005 gross biological emissions from agriculture, by 2030 – 50% by 2050).[4]

The assumptions we make of changes in land use in different scenarios include:

- Reference (no horticultural expansion);
- "Growing horticulture" (LH) (20% expansion of horticultural land (100,000 ha) by 2030 and 40% (200,000ha) by 2050) LURNZ[5];
- "Horticultural transformation" (HH) (100% expansion of horticultural land (500,000 ha) by 2030 and 200% (1 million ha) by 2050) in LURNZ;
- Mitigation technology breakthrough (Mit) in 2030 (reduces dairy livestock emissions 30%, sheep-beef by 20%); and
- Land-use changes allowed to occur endogenously (EH) (i.e. driven from within the model) towards arable and horticulture (only using NZFARM).

The two land-use models both produce results relating to land use and production, and GHG emissions. LURNZ also models emissions prices and NZFARM models profits. Further modelling using the ESSAM Computable General Equilibrium model is undertaken to understand potential impacts on employment and the macroeconomy. By combining the three models we are able to explore impacts that no one model can explore alone. By comparing results across models we can gain some insight into their robustness.

Results

The 2030 target is harder to achieve than the 2050 target but is still possible, even under the high-ambition scenario with no horticultural expansion. Within LURNZ the implicit emissions price required for the high-ambition scenario is higher for the 2030 target ($80 per tonne of CO2-e is required for the 2030 target relative to $62 for the 2050 target - all emission prices are in 2018 dollars). This is partially because the rate of emissions reduction required is much faster between 2018 and 2030 than between 2030 and 2050. Given that land-use change is a gradual process, a higher incentive is needed to achieve a high enough rate of forestry conversions to meet the 2030 target.

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[3] Reductions are in addition to reference case emissions.

[4] The reduction of net emissions by 30% below 2005 gross emissions by 2030 is New Zealand's target under the Paris Agreement.

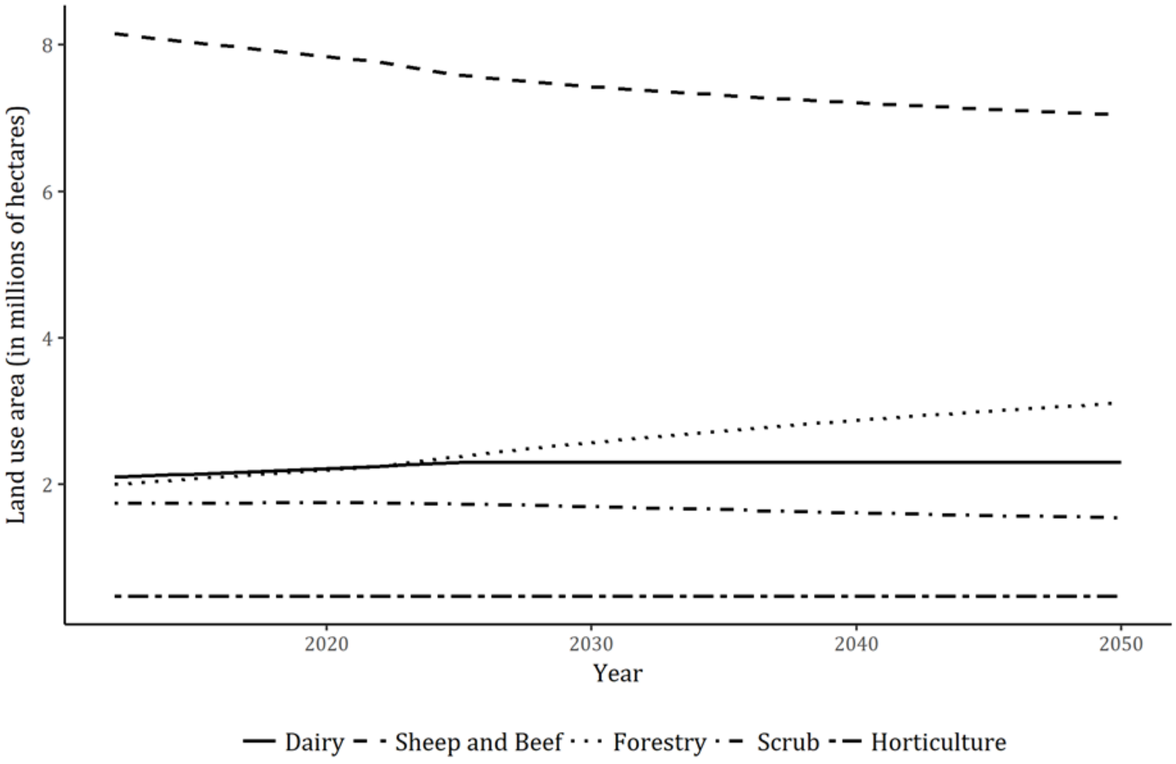
[5] Horticultural land is defined as including arable land for the definition of the scenarios as the LURNZ model does not distinguish between horticultural and arable.

Both models suggest that a large increase in forestry is needed to meet the targets in all scenarios (LURNZ requires an average of 58,000 ha per year of new planting in the high-ambition scenario, which is about double the rate in the reference case). In the LURNZ scenarios the increase in forest area is lowered significantly where there is a large expansion in horticulture or a new mitigation technology becomes available.

Scrub decreases in the high-ambition scenario as roughly half of new-planted forest area will come from scrub.[6] The historic decline in sheep and beef land continues but at a marginally higher rate relative to the period 2002–12 (6% decrease per decade relative to 7% in the high-ambition scenario).

The dairy area declines relative to the reference case in NZFARM with some conversion to horticulture and forestry. The horticultural area increase is due to the lower GHG emissions from these land uses compared with pastoral land uses and high profits (i.e. EBIT). In LURNZ the dairy area is reduced only by conversion to horticulture in the high-horticulture scenarios. Both models also show that sheep and beef area declines compared with the reference case. This is driven by the lower profit from sheep and beef land relative to dairy (and horticultural land uses in NZFARM).

ES 2 Dairy, sheep and beef, forestry, horticulture and scrubland in reference scenario, LURNZ model



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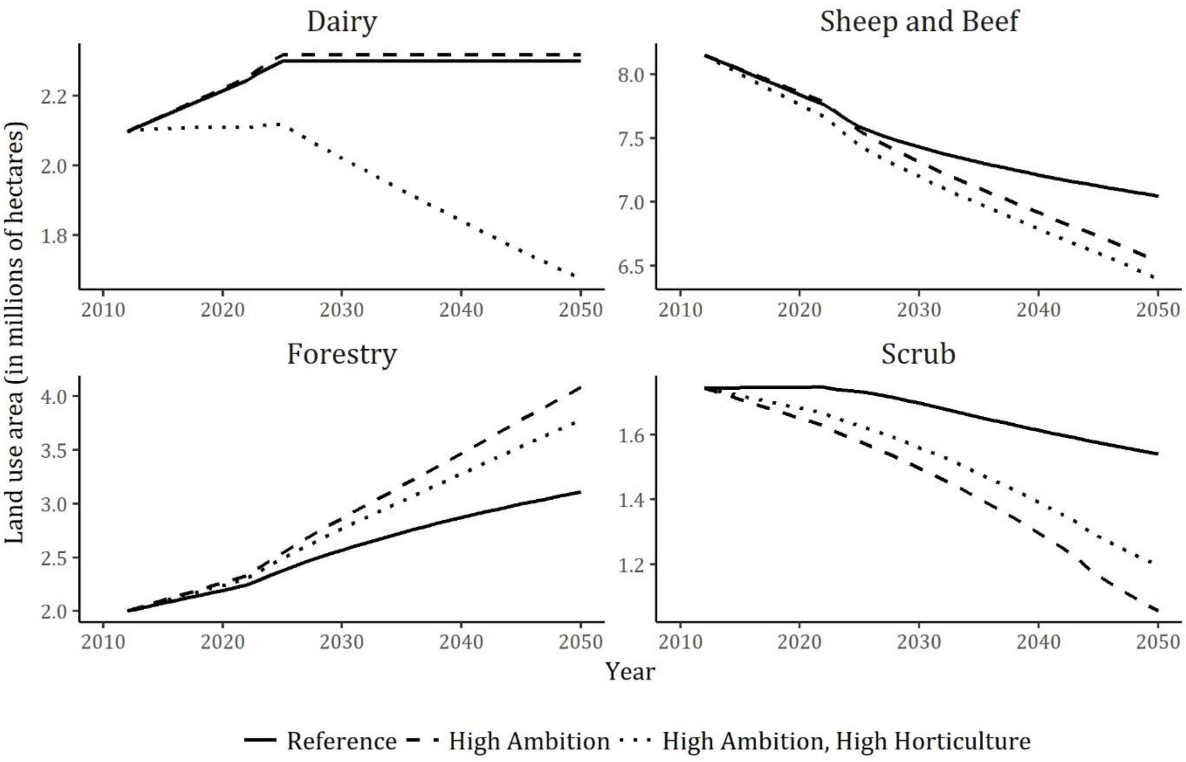
[6] ‘Scrub’ includes a wide range of non-forest or regenerating vegetation such gorse, Manuka, matagouri, fernland and sub-alpine scrubland but excludes ‘indigenous forest’. The precise definition is given in Anastastiadis et al, 2014.

ES 3 Dairy, sheep and beef, forestry, and scrubland use across three key scenarios, LURNZ – 2050 target

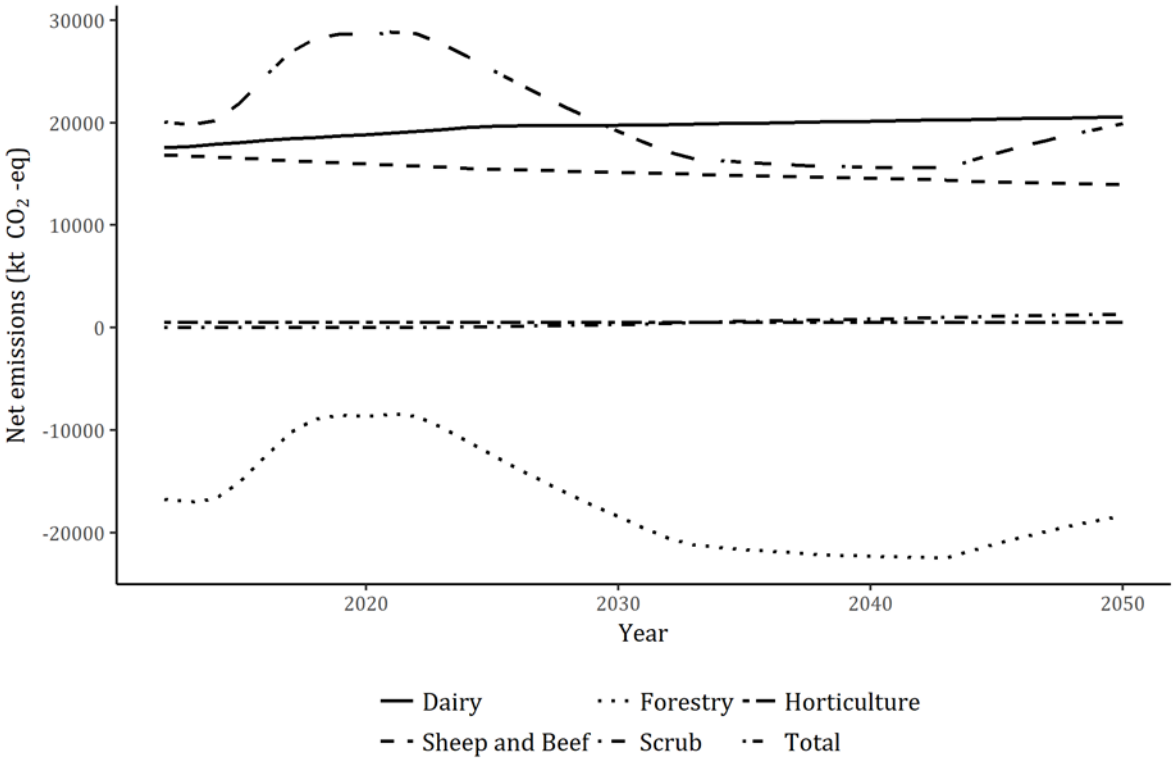


Note: Horticulture is not included because it changes only by assumption. It rises linearly to the target of 1 million ha in the High Horticulture, High ambition scenario. In other scenarios it is fixed.

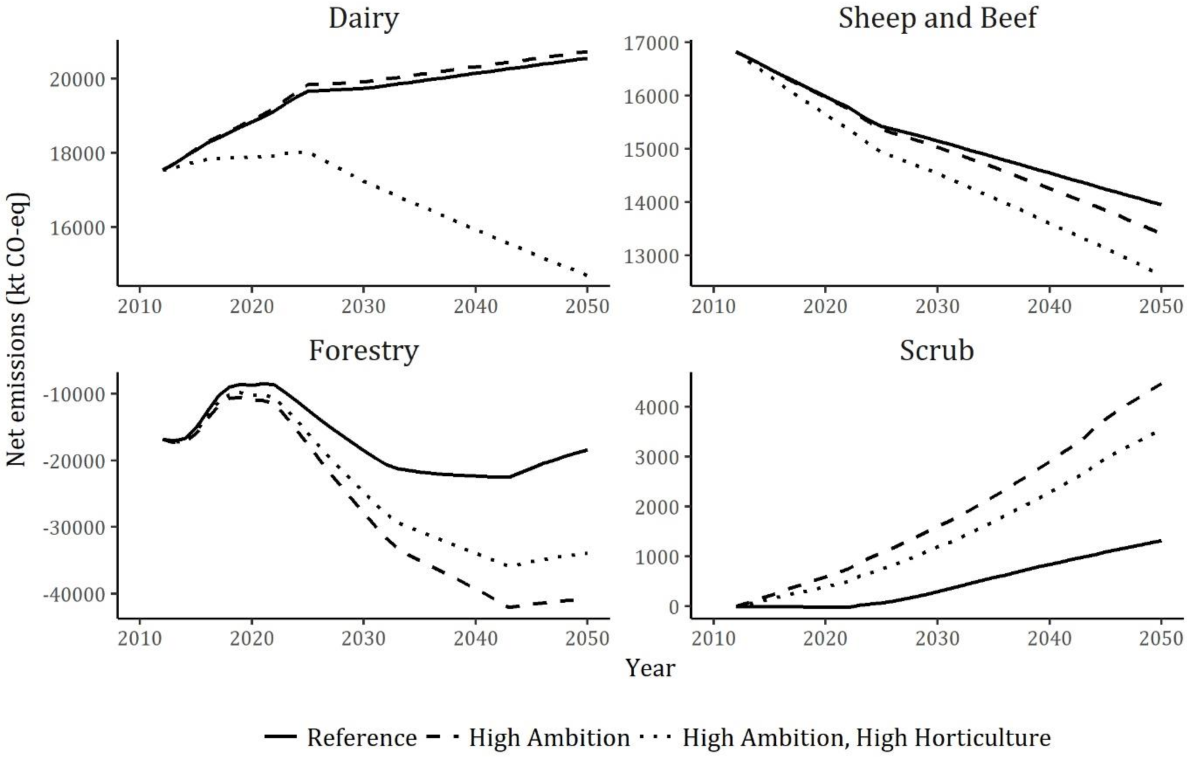
After 21 years, the first post-2012 forests reach their average long-term carbon stock. Further carbon sequestration in these forests will be offset later when these forests are harvested and carbon is released, unless they become permanent forests. Sequestration in new forests gradually stabilises and eventually cannot offset rising dairy emissions. We include continual increases in dairy productivity over time in our modelling, which leads to higher milk production and therefore higher emissions per hectare even though emissions efficiency is also improving. Net forestry emissions start rising again in the mid-2040s. New Zealand will therefore face significant challenges in meeting targets after 2050 if most net mitigation in the land-use sector is driven by expansion in rotation forestry.

In scenarios with no horticultural expansion, emissions from the dairy sector continue to rise, albeit at a lower rate. Only in the high-ambition scenario with high horticulture do dairy emissions fall, and even then, only after dairy conversions cease.

ES 4 Net emissions in reference case by sector, LURNZ



ES 5 Net emissions across three key scenarios by sector, LURNZ – 2050 target



Note: Horticulture is again excluded because it changes only by assumption.

A methane vaccine (or equivalent on-farm technology or practice change) has roughly the same effect on emissions prices and the area in forestry/scrub as the scenario where horticultural area increases by one million hectares. The required implicit emissions price in 2018, for the high-ambition scenario that meets the 2050 target, falls from around $63 to $50 with a vaccine.

In the high-ambition scenario the computable general equilibrium (CGE) analysis suggests that Gross Domestic Product (GDP) in 2050 is 0.6% higher than in the reference scenario, rising to 0.8% in the high-ambition, low-horticulture scenario and 1.3% in the high-ambition, high-horticulture scenario. In all cases the increase in real gross national disposable income (RGNDI) is more than the increase in GDP – up to double the amount in the high-ambition, high-horticulture scenario. The increases in RGNDI are pushed along by the improvements in the terms of trade. In the high-ambition, high-horticulture scenario private consumption increases by 3.4% over the reference case compared to 2.3% for exports. However, there must be a market for the new mix of products at prices that make them profitable to produce. Significant changes in training and local infrastructure are also required to enable large shifts towards horticulture.

In terms of gross output, in the high-ambition, high-horticulture scenario, horticulture expands by 212%, while sheep and beef and dairy decline by 13% and 28% respectively. For the high-ambition, low-horticulture scenario the changes are smaller as the shift to more horticulture is less marked. In the high-ambition scenario, the shifts are smaller still.

Total employment in the agricultural sectors in the reference case is 86,500 FTE, increasing to 136,900 FTE in the high-ambition, high-horticulture scenario. Employment losses in pastoral agriculture are more than offset by the expansion in horticulture. The high-ambition, low-horticulture scenario also has an increase in agricultural employment relative to the reference case, while in the HA scenario agricultural employment is virtually unchanged. Under the mitigation scenarios, NZFARM shows that the reduction in net land-use revenues in the pastoral sector is mostly offset by the increase in profit from horticulture and forestry.

Conclusions

Achieving the proposed 2050 target seems possible even with no additional on-farm mitigation through new technology. If however this is achieved without a structural shift toward horticulture, significant new mitigation technology, or establishment of significant permanent forests, these reductions will be difficult to sustain beyond 2050 because the potential for forestry expansion is ultimately limited. It seems likely that the 2030 target will be harder to meet because of the speed of change required.

An expansion of horticulture by one million hectares leads to emission reductions almost identical to those from a fully adopted methane vaccine (or similar new technology). If some combination of these can be achieved, large short and long-term emissions reductions in the land sector will be much more manageable.

The land-use changes in the scenarios are significant but are not unprecedented, except for the assumed expansion of horticulture in some LURNZ scenarios. Achieving the level of horticulture expansion modelled in the LURNZ scenarios is likely to require companion policies such as education and efforts to expand market access and overcome any trade barriers to new products. Consideration should be given to the non-price-related barriers to land-use change faced by farmers and Māori landowners.

The modelling suggests small losses of employment in the dairy and sheep-beef sectors as they expand less or gradually contract but these are more than offset by increases in forestry employment. If horticulture can expand rapidly, it brings large increases in employment. That could bring its own challenges.

NZFARM shows small impacts on New Zealand's profit (less than 1%) even for the high-ambition target.[7] Losses in the dairy and sheep-beef sectors are mostly offset by increased revenue from forestry and, to a lesser extent, horticulture. The CGE results suggest a small positive effect on the economy with the high-ambition scenario, and a larger positive effect if the horticultural sector expands. This increase largely results from a change in the terms of trade as we move towards the more profitable horticultural sector by expanding our international markets. The effects on other sectors of the economy were not a focus of this work.

Even if biological emissions from agriculture were included in the emissions trading system, the emissions price alone would be unlikely to be sufficient to induce large reductions in biological emissions through land-use change; non-price barriers could inhibit responses. Facilitating the transition of land towards horticulture and overcoming barriers for forestry (and native regeneration) to respond to the emissions price could make the transition a positive one for the rural sector.

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[7] Because NZFARM is not a dynamic model, achieving the 2050 target is independent of the cost of achieving the 2030 target. In contrast, in LURNZ the emissions prices between the two time periods is constrained to rise at the real rate of interest following the Hotelling principle for efficient asset pricing.

1 Introduction

As a consequence of climate change and the impact of agriculture on greenhouse gas (GHG) emissions, the Biological Emissions Reference Group (BERG) was established as a joint industry-government initiative. The aim of BERG is to collaboratively build a base of evidence on current and future opportunities to mitigate biological GHG emissions on-farm, together with the costs and opportunities of and the barriers to doing so.

The BERG commissioned this work to better understand the potential of land-use change to reduce GHG emissions to 2030 and 2050. The main project objective is to predict the likely extent and nature of land-use change as part of a cost-effective response to land-sector mitigation targets and the potential economic and social impacts of these changes. We also explore:

- how those land-use changes, and the intensity of effort required to achieve them, vary with the timing and stringency of targets and with different assumptions about new land uses and technology; and
- national impacts on gross domestic product (GDP), production of key export commodities, and employment.

To address the different components of the project, in this report we utilise a mix of literature review, modelling, econometrics, and qualitative approaches. Land-use change projections are created using a dynamic, empirically estimated land-use simulation model (LURNZ: Anastasiadis et al., 2014; Timar, 2016) and an agri-environmental economic optimisation model (NZFARM: Daigneault et al., 2018). We use the resulting changes in production from these models in an economy-wide computable general equilibrium (CGE) model (Infometrics, 2015) to estimate wider economic impacts. Likely social impacts are also discussed.

2 Scenarios for analysis

The main mitigation option to reduce GHG emissions from agriculture analysed in this work is land-use change.[8] The scenarios analysed are described in Table 1 (for LURNZ) and Table 2 (for NZFARM). As each model is underpinned by different algorithms, characteristics, and assumptions, it is not possible to model exactly the same scenarios for both. However, the scenarios are very close in nature and can therefore be compared usefully. Both models consider two main reduction pathways from the reference case: a low-ambition (reduction by 15% of 2005 gross agricultural GHGs by 2030 and 25% by 2050), and high-ambition one (30% by 2030 and 50% by2050).

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[8] The initial component of this report was a workshop held with the Ministry for Primary Industries (MPI) and the BERG in August 2017. This workshop defined a set of scenarios to be analysed and the main assumptions to be used.

The estimated effect of commodity prices on the shares of land use in pastoral, forestry, and scrub underpins LURNZ simulations. Emissions prices flow through to changes in these three land uses via adjustments to commodity prices. Therefore, for this project LURNZ effectively converts pasture and scrub to forestry until the mitigation targets are achieved. Additional scenarios for LURNZ also allow broader land-use change towards horticulture (which includes cropping and arable). Expansions in horticulture would not in reality be expected to primarily occur in either cropping or arable but rather in export products such as fruit or viticulture.

In a final LURNZ scenario, we consider a technological breakthrough such as a methane vaccine that helps reduce emissions from livestock farming. It is assumed that the technology becomes available after 2030 and that it reduces livestock emissions by 30% for dairy and by 20% for sheep-beef, which equates to approximately 22% and 17% of total biological emissions from the sectors respectively. The technology affects both economic incentives for land-use change (so commodity prices are adjusted to reflect the change in emissions intensity) and GHG emissions from the pastoral sectors. The adjustments to both commodity prices and emissions are made with the assumption that the new technology affects only the livestock component of each sector's emissions and that it is fully adopted with no cost in both sectors as soon as it becomes available. These are obviously strong assumptions.

Table 1. Scenarios modelled in LURNZ

Land-use Assumptions	**Reference Case: no ambition for agriculture sector – existing ETS**	**High-ambition Scenario: 30% net land-sector emissions reduction by 2030 – 50% by 2050**	**Low-ambition Scenario: 15% net land-sector emissions reduction by 2030 – 25% by 2050**
Reference: No horticultural expansion	Reference	High ambition (HA)	Low ambition(LA)
"Growing horticulture" 20% expansion of horticultural land by 2030 and 40% by 2050		High ambition, low hort (HALH)	Low ambition, low hort (LALH)
"Horticultural transformation" 100% expansion of horticultural land (~500,000 ha) by 2030 and 200% (~1million ha) by 2050		High ambition, high hort (HAHH)	
Mitigation technology breakthrough in 2030 reduces dairy emissions 30%, sheep-beef by 20%		High ambition, mitigation (HAMit)	

Notes: Shaded areas represent the scenarios. Horticultural expansion simulations are imposed across the different scenarios rather than being optimised based on the target. Horticultural land is defined to include arable land for the definition of the scenarios as the LURNZ model does not distinguish between horticultural and arable.

Table 2. NZFARM scenarios with endogenous changes in horticultural area (EH).

Each shaded cell represents one scenario to be analysed.

Land-use Assumptions	**Reference: no ambition for agricultural sector**	**High ambition: 30% net land-sector emissions reduction by 2030 – 50% by 2050**	**Low ambition: 15% net land-sector emissions reduction by 2030 – 25% by 2050**
Reference: No horticultural expansion (from LURNZ)	Reference		
Scenario: Land-use changes allowed between dairy, drystock, arable, horticulture and forest		All land-use change is endogenously determined – High-ambition, endogenous horticulture (HAEH)	All land-use change is endogenously determined – Low-ambition, endogenous horticulture (LAEH)

Note: Shaded areas represent the scenarios. Horticulture in NZFARM is endogenous – determined by the model.

2.1 Establishing emissions targets for the low- and high-ambition scenarios

The emissions targets for 2030 and 2050 are defined by first calculating tonnes of emissions reductions based on percentages of 2005 agricultural emissions. These reductions are then subtracted from the projected emissions in the reference case. In 2005 the gross emissions from agriculture reached 39,114.6 kilotonnes of CO_2-equivalent (kt CO_2-e) (Ministry for the Environment (MfE), 2018a). Therefore, the net emissions targets are calculated as follows.

- For the high-ambition scenario target of 30% reduction in emissions by 2030, we calculated 30% of 2005 **gross** agricultural emissions (= 11,734 kt CO_2-e), based on NZ GHG inventory (MfE, 2017a, 2018a). The 2030 target is thus for **net** agricultural and forestry emissions to be 11,734 kt CO_2-e below the reference case.[9]
- For the low-ambition scenario, the target is 15% reduction in emissions by 2030. Therefore, considering 15% of 2005 **gross** agricultural emissions = 5,867 kt CO_2-e of sequestration, 25% and 50% targets for 2050 are calculated similarly (see Table 3 for numbers).

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[9] All sequestration in forestry that is additional to the reference case is hence attributed to the agricultural sector. Without this assumption the changes in gross biological emissions from agriculture would need to be much larger with consequently much larger land-use changes and implicit emissions prices.

The motivation behind this formulation of the targets is to simulate the land-use change required to achieve land-sector mitigation. This would be above what would be induced by the current ETS (that is, forestry is included and agricultural emissions excluded) and is roughly in line with national all-sector mitigation targets. Emissions reductions as land moves out of pastoral uses into other less intensive GHG-emissions land uses and forestry carbon sequestration are used meet the target. No additional on-farm mitigation is simulated within this project (except in one scenario where it is imposed by assumption); stocking rates, dairy production per hectare, and emissions intensity per unit of production are the same across all scenarios. Dairy production per hectare rises over time and emissions intensity in sheep-beef and dairy falls, but equally in all scenarios. The mitigation targets are shown in numbers in Table 3. and indicated on Figure 3.

Table 3. Scenario net emissions targets, in kt of CO_2 equivalent

Net Emissions (kt CO_2-eq)	**2012**	**2030**	**2050**
Reference case*	20,060	19,159	19,891
Low-ambition reduction (derived from 2005 levels)	0	5,867	9,779
High-ambition reduction (derived from 2005 levels)	0	11,734	19,557

Note: *Emissions in 2030 and 2050 derived with LURNZ (See next section for detailed results.) We include a constant 1,948 kt CO_2-eq of “other agriculture” emissions for each year in the total emissions series to account for emissions not in the dairy, sheep and beef, horticulture, or forestry sectors.

2.1.1 Why choose 2005 levels as targets?

For this project we consider a reduction target based on the gross emissions from agriculture in 2005. Thus, the target for the high-ambition scenario (30% reduction by 2030) aligns with New Zealand’s “Nationally Determined Contribution” to reduce GHG emissions by 30% below 2005 levels by 2030 (MfE, 2018b).

The composition of GHG emissions in 2005 across land sectors differed significantly from the 2016 emissions profile. For example, emissions from sheep were around 30% of the total gross agricultural emissions in 2005 (~11,800 kt CO_2-e), but only 23% of emissions in 2015 (~8,700 kt CO_2-e out of 38,400 kt CO_2-e produced by agriculture in total). However, we target the 2005 emissions as an aggregated “land-based” emissions level. The modelling does not purport to consider the efficient allocation of reduction efforts to the land sector as a whole. Nor does it suggest that any costs of achieving these reductions should be borne in any particular way either between the land sector and the rest of the economy or between specific sectors within the land sector.

2.2 Reference case assumptions

A reference case scenario (following a "business as usual pattern'', i.e. assuming no important changes to current policy or land-use trends and drivers) was generated using LURNZ and used in both models. This scenario provides a reference case against which the other model runs in LURNZ and in NZFARM are compared.

Table 4. Assumptions for reference case

	Reference Case
Emissions Price Pathway	Observed prices until 2017, $25 from 2018[10] increasing at real interest rate annually thereafter (approx. 1.8%).
ETS Coverage	Agriculture not in ETS, reward for forest sequestration only. No other policies to incentivise land use change.
Commodity Prices and Interest Rates	Commodity price forecasts from the "Situation and Outlook for Primary Industries" 2017.[11] Prices held constant beyond last projection year. The nominal interest rate is the 90-day bank bill rate.[12]
Emissions Intensity	Continuous improvement (year on year) in the efficiency of GHG emissions per unit of product, reflecting past trend (see details below).
Forestry Sequestration	Payments to 21 years based on National Inventory lookup table. Average annual rate is 31.83t CO_2/ha. No payments/penalties thereafter. No deforestation as forestry is always modelled to expand.
Scrub/Native Sequestration	6.5t CO_2/ha emissions or sequestration for each hectare change in total area throughout simulation period.
Dairy Area	No new conversions from 2025.
Horticulture Emissions	1.0 t CO_2-e/ha[13]
Horticulture Area	Constant
Urban Area	Constant

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[10] In 2018 New Zealand dollars.

[11] Ministry for Primary Industries (2017). Prices are all deflated to 2008 NZ dollars using the CPI (year to June) and CPI projections (Treasury, 2017).

[12] It is projected from 2017 to 2021 using the Treasury (2017). The 2021 rate is maintained for the rest of the scenario. Real interest rates are the nominal 90-day bank bill rate minus CPI projections, also maintained after 2021. This gives a real interest rate of 1.8% from 2021 onwards.

[13] This assumption is based on data provided by Brent Clothier of Plant and Food Research. Kiwi fruit have emissions of 1.03 t CO2e/ha; arable of 0.95 t CO2e/ha; apples of 0.71 and grapes of 0.17. New Zealand's Future Horticultural & Arable Landscapes: Now, Potential, Constraints, & the Impact of Resource Pricing. Presentation at Plant and Food Research Workshop, Palmerston North, 7 June, 2018

2.2.1 Freshwater policy

For the reference case we assume that there are no new dairy conversions from 2025, as the National Policy Statement for Freshwater Management (MfE, 2014) must be implemented by that year. Therefore, dairy conversions are likely to be highly restricted from that point onwards. Otherwise, freshwater policy reforms are not included in any scenarios. Freshwater policy and its implications for climate policy was modelled in a recent report (Daigneault et al., 2016). The modelling does not consider the effects of the National Environmental Standards for Plantation Forestry that came into force in May 2018.

2.2.2 Production and emissions factors for reference case (LURNZ only)

Production of milk solids for each Livestock Improvement Corporation (LIC) region is determined per cow by taking the 5-year average milk-solid production between 2010 and 2014 in the region.[14] This is used as the base milk-solid production level for 2012. Production per cow for each region is then increased at the national growth rate projected by Reisinger and Clark (2016) in their minimum production increase scenario. These numbers are close to the projections provided by DairyNZ's Economics Group and the projections to 2030 in the *Seventh National Communication* (MfE, 2017b). Regional stocking rates are held constant at the default numbers in LURNZ (Timar and Kerr, 2014), as stocking rates have not changed significantly in recent years. We then use Reisinger and Clark's (2016) projected national emissions factors per kilogram of milk-solids to calculate emissions.

Sheep and beef emissions (and deer[15]) are from Timar and Kerr (2014) but adjusted to use AR4 metrics instead of AR2 metrics.[16] Wool emissions were also added to sheep stock units, by assuming a ratio of 4:7 of wool emissions to meat emissions, as reported on an aggregate level by Timar and Kerr (2014). Therefore, sheep emissions were scaled up by 4/7. The emissions factors are lowered over time using Reisinger and Clark's (2016) projected improvements in emissions factors for sheep and beef in their minimum efficiency scenario. No production increases (increases in stock units per ha) over time are included.

Forestry net sequestration is calculated using an "averaging" approach (see Appendix A for details). Net scrub emissions in 2012 are assumed to be zero. Sequestration on land that transitions into scrub after 2012 is assumed to be 6.5 tonnes of CO_2 per hectare, per year. If

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[14] Retrieved from https://www.dairynz.co.nz/publications/dairy-industry, New Zealand dairy statistics reports.

[15] Land used for deer is incorporated in sheep and beef land in LURNZ, so the same emissions per hectare will be applied.

[16] AR2 and AR4 refer to assessment reports numbers two and four from the Intergovernmental Panel on Climate Change (IPCC) and the metrics, or conversion rates, between GHGs from the reports. The conversion rates are 21 and 25 from one tonne of methane to tonnes of CO_2 respectively, and 310 and 298 for one tonne of nitrous oxide to CO_2, respectively. AR4 metrics are currently used for accounting purposes under the United Nations Framework Convention on Climate Change (UNFCCC).

land transitions out of scrub after 2012, 6.5 tonnes of CO_2 per hectare, per year are assumed to be lost, i.e. the opportunity for that land to sequester CO_2 is lost.[17]

NZFARM uses different emission factors. These are detailed in Appendix B. Neither model accounts for changes in soil carbon storage.[18]

3 Land-use change models: LURNZ and NZFARM

In this work we explore likely land-use change in response to climate policy using the two main economic land-use models available in New Zealand: Motu's **Land Use in Rural New Zealand** model (LURNZ) and Manaaki Whenua Landcare Research's **New Zealand Forestry and Agricultural Regional Model** (NZFARM). More detailed information about each model is provided in the Appendices.

Using the two models allows results to be compared to see how robust they are to different model frameworks, input data, and assumptions. Both models use the same land-use reference case, which facilitates comparability across model runs. Neither model incorporates the potential impacts of climate change on land-use allocation.

3.1 The LURNZ model

The first model we used is LURNZ, which has been widely used across different studies in New Zealand (e.g. Anastasiadis and Kerr, 2013) and was empirically and spatially validated in the comprehensive study of Anastasiadis et al. (2014). The LURNZ model focuses on the major land uses (sheep-beef, dairy, plantation forestry, and native scrub and forest). Changes in the share of land in horticulture are imposed as scenario assumptions.

LURNZ is a national land-use model that simulates land-use changes and GHG emissions under a variety of user-determined scenarios (including a reference case) at an annual time step and at a fine spatial scale (500 m X 500 m). Comparison across scenarios allows exploration of the effects of different policy settings or different states of the world. The main strength of LURNZ is that it is based on two econometric models: a historical rural land-use change in New Zealand in response to commodity price changes (Kerr and Olssen, 2012) and a

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[17] This assumption is made to ensure net scrub emissions from a change in total area of scrub are accounted for. We need to make a simple assumption because of the lack of good information about the age profile of scrub and because we cannot predict the age of scrub that is cleared. The annual sequestration figure is from Carver and Kerr's (2017) calculation of the average sequestration of native forest per year over a 50-year period. As scrub is assigned last in the LURNZ Land Use Allocation module algorithm, scrubland tends to be modelled as shifting a lot over time. This is very unlikely to reflect reality. However, the total land area covered by scrub is less subject to change, so this simple assumption does not have large implications.

[18] Based on the estimates used to generate the 2018 National Inventory (Table 6.3.2), loss of soil carbon as land moves out of pasture could lead to temporary but significant changes in our results, particularly for low producing grassland that transitions into forest. Changing from high producing grassland to perennial cropland would result in the emission of 3.1 t CO2/ha per year for 20 years. This may not be a common transition given the types of horticulture that are likely to expand in New Zealand. Transition from high producing grassland to forest loses 2.4-2.5 tCO2/ha and from low-producing grassland to forest, which is likely to be more common, the soil carbon loss is 2.5-2.6tCO2/ha per year.

spatial choice logit model of land uses (Timar, 2011). Using these estimated historical relationships, the model simulates future land use and its location at a 25 hectare (500 m X 500 m) scale. The model dynamically simulates land-use change in response to changes in returns for dairy, sheep and beef, forestry and scrub. It simulates the potential impacts of climate change mitigation policies, or similar shocks, to these land-use patterns. The model also generates GHG emissions consistent with the National Inventory for the aforementioned land-use types (Timar and Kerr, 2014). More detail about the model is given in Appendix A.

3.2 The NZFARM model

The second model used, NZFARM, has been used to assess climate and water policy scenarios across New Zealand (e.g. Daigneault et al., 2012; Daigneault et al., 2016; Daigneault, Greenhalgh, and Samarasinghe, 2018). NZFARM is a comparative-static and non-linear mathematical programming model that simulates the agricultural and forestry sectors of New Zealand. It maximises the profit from agricultural/forestry production subject to feasible land-use and land-management options. NZFARM facilitates a “what if” scenario analysis by showing how changes in environmental policy (e.g. GHG emissions targets) could affect land use. It also shows the subsequent spill-over effects on a group of performance indicators important to decision makers and stakeholders. The “what if” analyses are performed by solving for a baseline/reference (or status quo) economic equilibrium, then imposing specific policy or other changes on the system and solving the model again to compute a new economic equilibrium consistent with the scenario changes. Performance indicators tracked within NZFARM include economic variables (e.g. productivity and EBIT) and environmental variables (e.g. carbon sequestration, GHG emissions). More detail on the NZFARM model is given in Appendix B.

4 Results from land-use models

The two models both produce results relating to land use, GHG emissions and production. LURNZ also simulates implicit emission prices and is used to simulate employment. NZFARM simulates profits. Tables with more detailed results are available in Appendix E: Detailed results.

4.1 The reference case results – derived using LURNZ

The reference case scenario was derived using LURNZ. This reference case was developed so the mitigation scenarios could be expressed relative to this.

The land-use simulations from 2012 to 2050 show a 9.6% increase in dairy area, a 13.6% decrease in sheep and beef, a 55.3% increase in forestry, and an 11.7% decrease in scrub. All other land is held constant by assumption. These land-use simulations are summarised in Table 5 and 6 and Figure 1 and

Figure 2.

Table 5. Reference case projections of land use in New Zealand (millions of hectares)

Land-use Category	2012	2030	2050
Dairy	2.10	2.30	2.30
Sheep and beef	8.15	7.43	7.05
Forestry	2.00	2.57	3.11
Scrub	1.74	1.70	1.54
Horticulture[19]	0.47	0.47	0.47
Non-productive and other private land[20]	2.16	2.16	2.16
Indigenous forest	1.69	1.69	1.69
DoC and public land	8.09	8.09	8.09
Pasture on public land	0.43	0.43	0.43
Exotic forest on public land	0.04	0.04	0.04
Total	26.88	26.88	26.88

Table 6. Reference case projections of land use in New Zealand (shares of total land)

Land-use Category	Share (%)			Change from 2012 (%)	
	2012	2030	2050	2030	2050
Dairy	7.8	8.6	8.6	9.6	9.6
Sheep and beef	30.3	27.6	26.2	-8.8	-13.6
Forestry	7.4	9.6	11.6	28.3	55.3
Scrub	6.5	6.3	5.7	-2.7	-11.7
Horticulture	1.8	1.8	1.8	0.0	0.0
Other[21]	46.2	46.2	46.2	0.0	0.0

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[19] Land in horticulture includes arable land in the LURNZ model.

[20] Pasture used by deer is held constant and included in "other private land".

[21] Includes non-productive and other private land, indigenous forest, DoC and public land, pasture on public land, and exotic forest on public land. Land area attributed to these use categories has changed historically, particularly with the expansion of the DOC estate and other reserves, but is held constant for the period 2012–2050 in the reference case projections.

Figure 1. Historical and reference case projections of major land uses in New Zealand (millions of hectares)

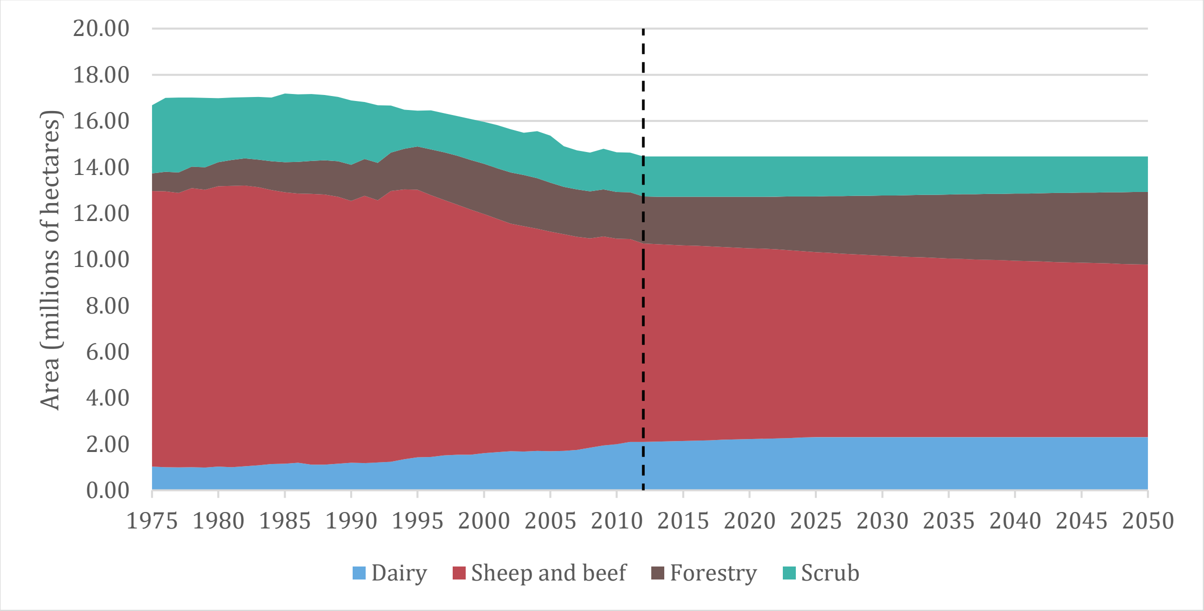
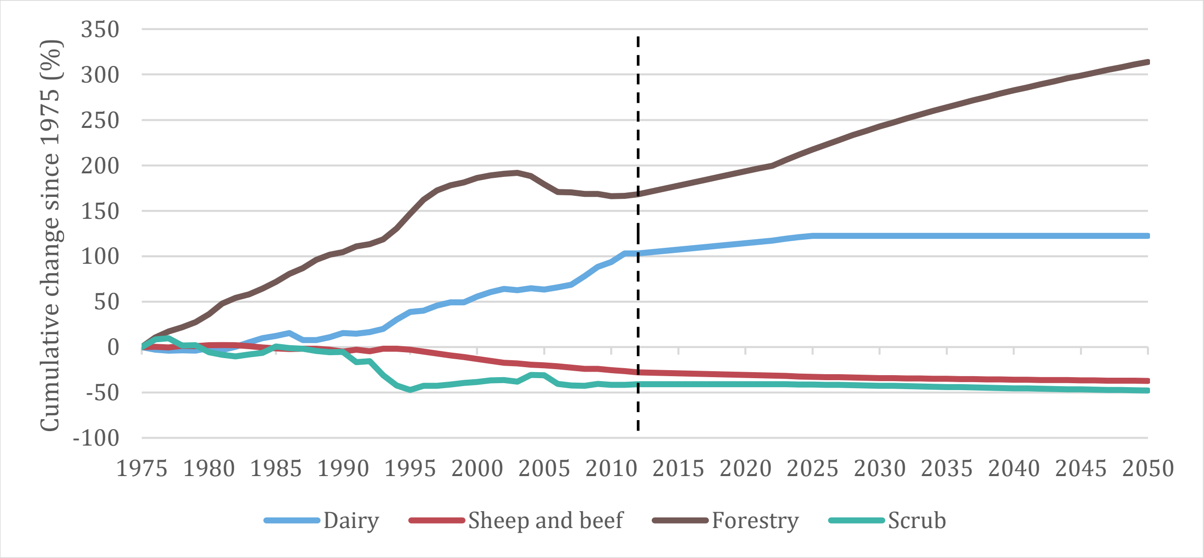


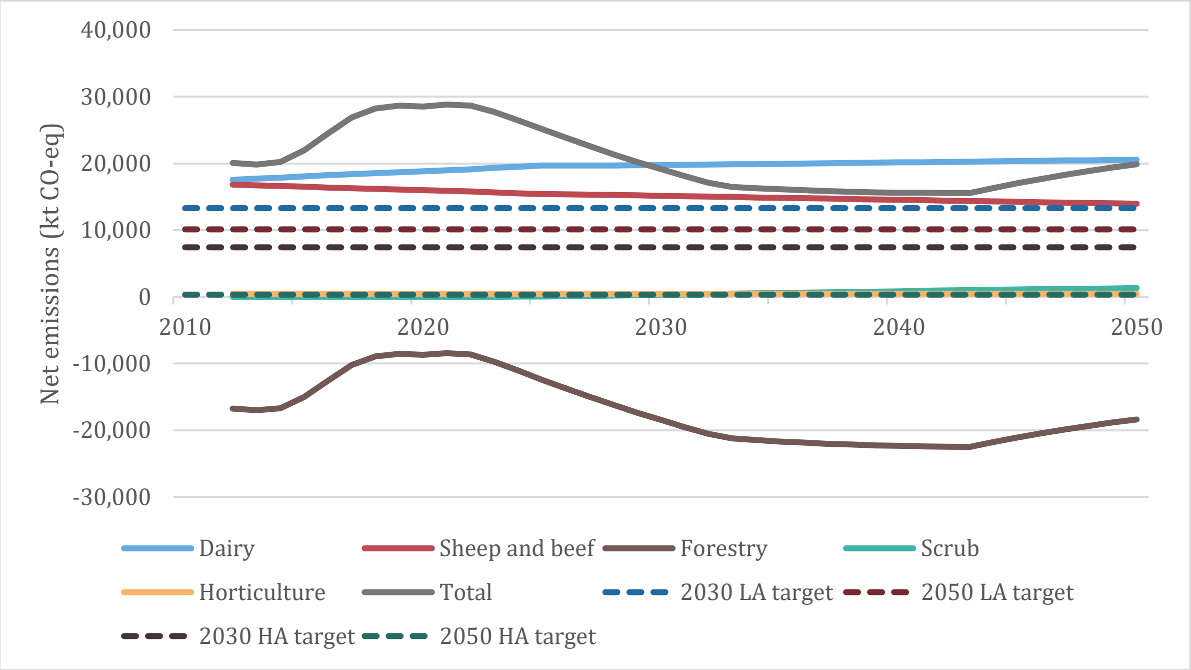
Figure 2. Cumulative change in historical and reference case projections of land use in New Zealand since 1975 (% points)



The land-use change in the reference case is a result of the commodity price inputs and the ETS reward for forestry sequestration as they affect the dynamic Land Use Change module in LURNZ. Forestry conversions, which return roughly to average historical levels, are largely driven by the more favourable conditions for forestry with the ETS reward for sequestration. Sheep and beef land continues to decline, though at only half the rate of the previous 10 years.

Emissions by land use are shown in Figure 5. Dairy emissions are increasing along with the increase in dairy area nationally. Overall, dairy emissions increase by 17%, compared with an increase in dairy area of 9.6%. Dairy emissions increase per hectare because, although emissions per litre of milk produced are declining, the amount of milk produced per cow is increasing faster (Reisinger and Clark, 2016). Stocking rates are assumed to hold constant and therefore emissions per hectare increase. Sheep and beef emissions fall faster than the drop in sheep and beef land area due to increased efficiency in production, while production is assumed to hold constant per hectare.[22] Scrub emissions are small but increasing due to the net loss in scrubland area. Net forestry emissions are driven by the growth pattern of the additional post-2012 forest, the increase in forest planting after 2016 when the ETS price begins to rise, and the fact that forest sequestration stops being counted once the forest is 21 years old.[23]

Figure 3. Net emissions in the reference case scenario (and targets)



Note: we include a constant 1,948 kt CO_2-eq of "other agriculture" emissions for each year in the total emissions series to account for emissions not in the dairy, sheep and beef, horticulture, or forestry sectors.

4.2 Mitigation scenario results from LURNZ

4.2.1 Emissions prices: explicit and implicit

We present emissions prices first because they are key drivers of the land use and hence emissions changes in each sector. These emissions prices are applied explicitly for forestry and scrub and implicitly for biological emissions in order to simulate changes in land use that are

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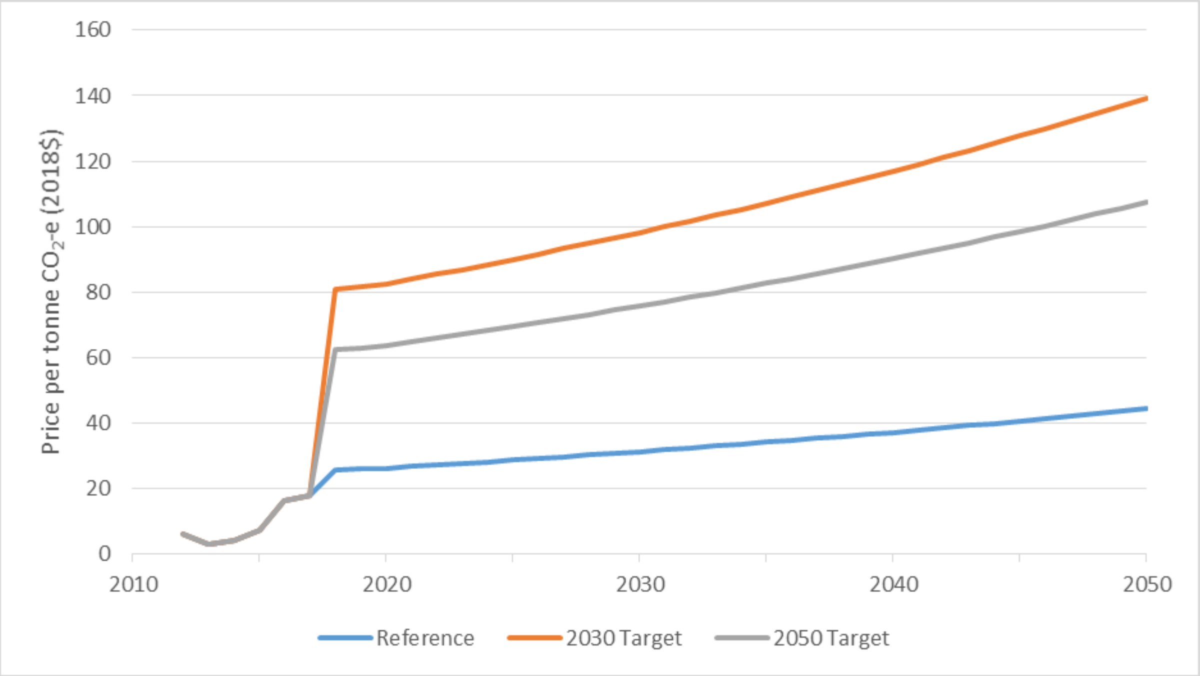
[22] The drop in emissions intensity of beef production is also partly due to the accounting method for beef emissions in the national inventory, given its relationship with the dairy sector. For example, an expanded dairy sector leads to more dairy cow offspring entering the beef sector. The initial growth of these offspring is accounted for in dairy emissions. We use Reisinger and Clark's (2016) minimum efficiency scenario to calculate the changes in emissions factors across the dairy and beef and sheep sectors for consistency and simplicity.

[23] Deforestation is assumed not to occur after 2012, despite positive deforestation in recent years when ETS prices were low. Historically when ETS prices exceeded $20, no deforestation was planned (Carver, Dawson, and Kerr, 2017).

likely to result from policy encouraging efficient land use. In the reference case a price is applied only to forestry and scrub.

The scenarios are structured to achieve one of the targets in the most efficient way possible over time (not necessarily the 2030 target and then the 2050 after that); the emissions price jumps up in 2018 and then rises at a steady rate throughout. The rate of required reduction annually is roughly twice as high for the 2030 target relative to the 2050 target, so the emissions price required is much higher. The high-ambition, no horticultural expansion (HA) path, which reduces net emissions by 30% by 2030 and (over) 50% by 2050, requires that emissions prices rise to $80/tCO2-e immediately then continue to rise to $140 by 2050. To meet the 2050 target but not the 2030 target, the high-ambition path with no horticultural expansion would require emissions prices to rise to over $60 immediately and that farmers respond as though the biological emissions from their livestock are similarly priced. This lower price path achieves only half of the desired reductions by 2030.

Figure 4. Emissions price projections in the HA scenario with 2030 and 2050 targets



For the rest of the report we focus on paths that meet the 2050 target only. The full results are available in an on-line excel spreadsheet.[24]

The emissions price paths required to meet the target in 2050 under each scenario are shown in Figure 5. If New Zealand is able to double horticultural area by 2030 and triple it by 2050 (an expansion of almost one million hectares), the emissions price required now to achieve the high-ambition scenario would fall from $60 to around $48 and the price required

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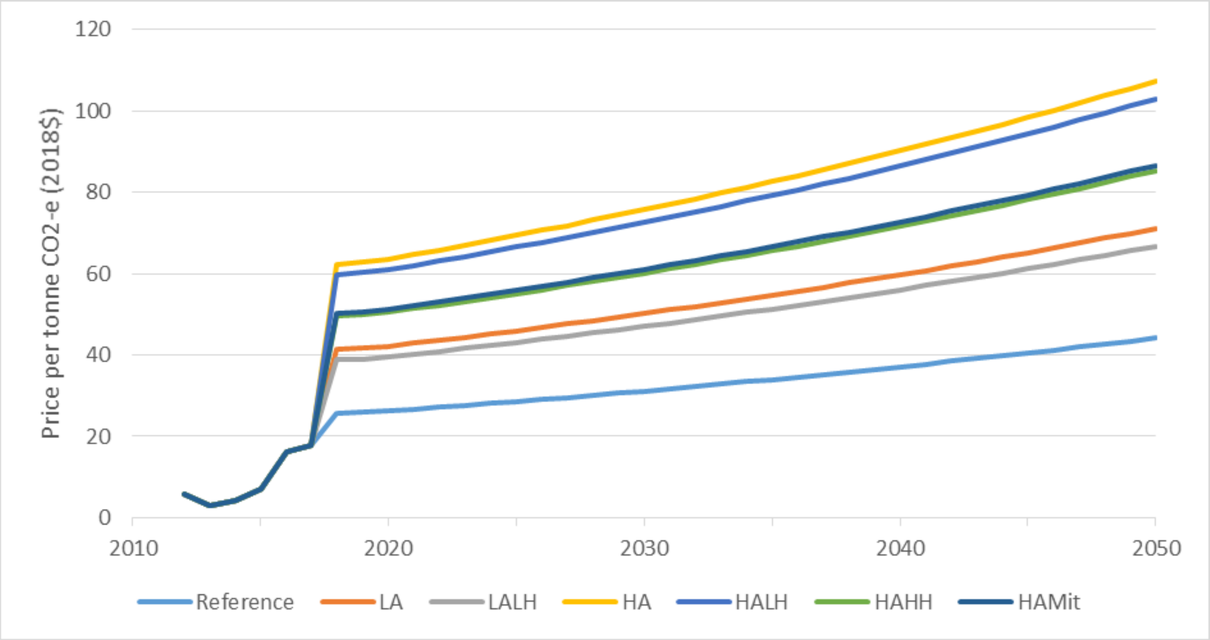
[24] https://motu.nz/our-work/environment-and-resources/lurnz/land-use-change-as-a-mitigation-for-climate-change

by 2050 to around $83. This is very close to the effect on required implicit emissions prices from a breakthrough mitigation technology fully implemented in 2030. Horticulture, however, will be even more effective as a mitigation option over time because sheep-beef land continues to contract as forestry expands, so there are fewer animals whose emissions can be lowered by the technology. Both options could be used simultaneously, which would lower costs further.

Figure 5. Emissions price under each scenario to meet the 2050 target.



4.2.2 *Land-use change (2050 target)*

The total land-use areas for each category under all scenarios in 2030 and 2050 are shown in Table 19 in Appendix E: Detailed results. For each scenario the combination of land uses meets the net land-use emissions targets as established in Table 3. We now consider how each land use is affected by the scenarios that meet the 2050 target only. The scenarios that meet the 2030 target would lead to more land-use change in every year.

Changes in the area occupied by horticulture are defined by the scenario and horticultural area is assumed to grow linearly. The Land Use Allocation module determines where the horticultural land is located. It locates horticulture on the land most suited to horticulture, whatever the previous land use.[25] Given horticulture tends to be located on the best land, as does dairy, the horticultural expansion is mainly onto dairy land. Hence, there is less dairying when there is horticultural expansion. This reduction in dairy land in turn leads to lower emissions, meaning less forestry expansion is required to meet the mitigation targets.

Both low- and high-ambition targets lead to no change in dairy land if horticulture is held constant. If there is a significant shift towards horticulture, the shift likely will involve

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[25] If the previous land use is one of dairy, sheep and beef, or scrub or if the area in forestry is decreasing.

conversions from dairy land. In the most extreme horticultural scenario (HAHH: high ambition, high horticulture), dairy shrinks significantly from 2.1 million hectares in 2012 to 1.7 million hectares in 2050. This equates to a reduction of about 27% in dairy land compared to the reference case.

The total area of additional land converted from sheep and beef pasture to other uses by 2050 in the most extreme scenario (HAHH) is similar to the conversion out of dairy. The percentage changes are much smaller than for dairy, however. Conversion of sheep-beef pasture is mostly driven by the level of policy ambition and less so by conversion to horticulture. The direct conversion of sheep and beef land to horticulture is partly offset by lower emissions prices that put less pressure on sheep and beef farmers to convert land. The introduction of a breakthrough technology reduces pressure to move out of sheep-beef land much more than an expansion in horticulture does. The reduction in pressure for change in sheep-beef land when a new technology is introduced is similar to the effect of moving from the high-ambition target to the lower ambition target.

Forestry expansion is almost entirely driven by the level of ambition, roughly doubling with a move from low to high ambition, i.e. proportional to net emissions reductions. Without on-farm mitigation, and with no horticultural expansion, major increases in forestry are required to meet the net emissions targets. On average, from 2018–50 in the HA scenario, 58 thousand hectares per year (and up to 72 thousand hectares) of new planting are needed. This is 23% higher than the average afforestation between 1975 and 2000, (47 thousand hectares) but not historically unprecedented. For three years running in the early 1990s, more than 72 thousand hectares of new forest was planted per year.[26] The increase in forestry land is at the expense of sheep and beef and scrubland.

When horticulture expands, the level of forestry expansions required to meet the target falls. Forestry expansion in high-ambition, high-horticulture by 2050 is roughly halfway between the low-ambition and high-ambition scenarios without horticulture, even though the mitigation target is much more stringent under high ambition compared with low ambition.

The mitigation technology has almost exactly the same effect on forestry expansion as the one million additional hectares of horticulture. This is not surprising given that their effect on emissions prices is similar.

Because scrub mainly competes with plantation forestry, the area of scrub reduces as the level of ambition rises. In contrast to the other land uses, horticultural expansion leads to higher levels of scrub – or, more precisely, lower levels of loss of scrub. As with forestry, the technology has very similar effects as the high level of horticulture but this time increasing scrub.

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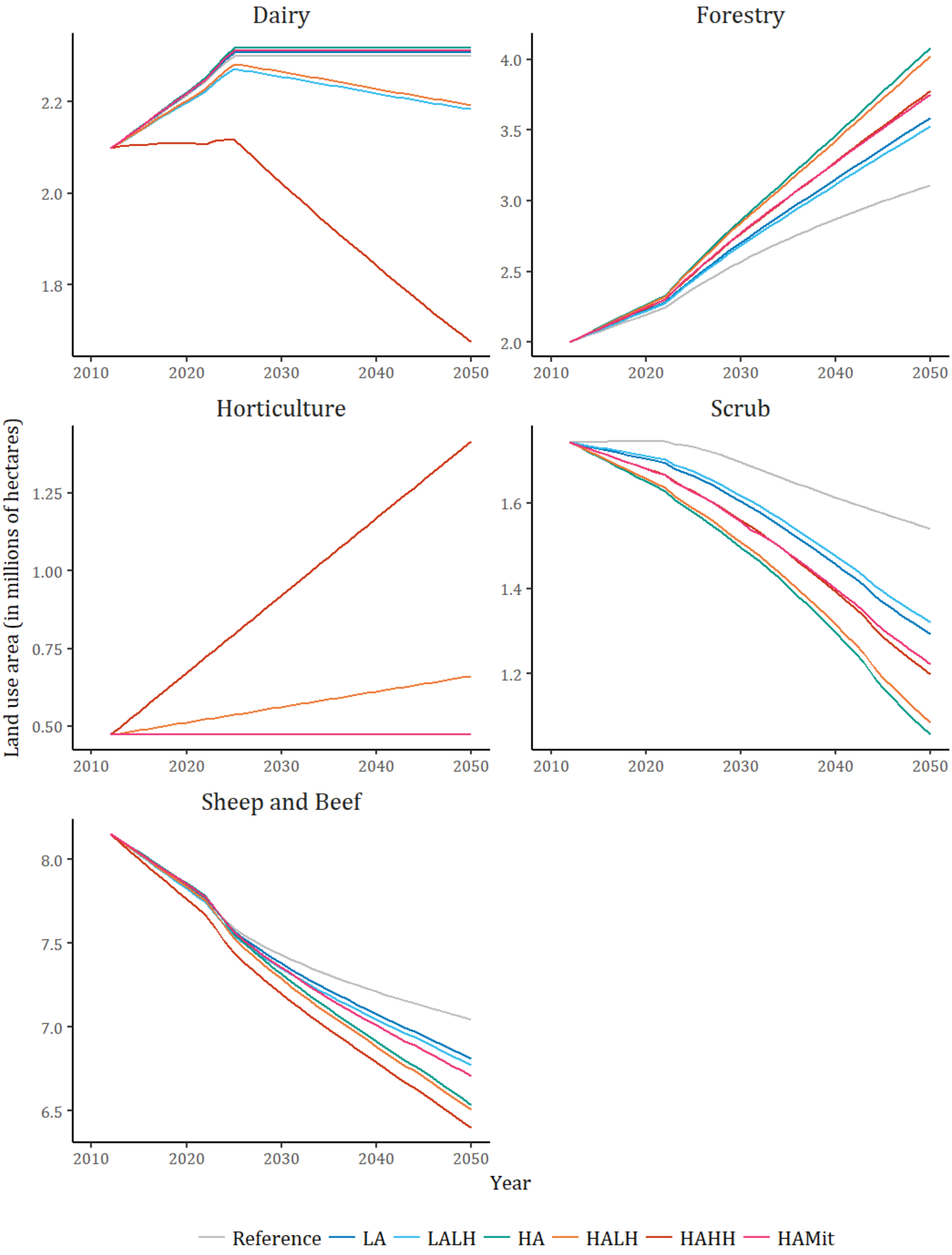
[26] Data from NEFD. Reports available at www.mpi.govt.nz.

Figure 6. Dairy, forestry, horticulture, sheep and beef, and scrubland use across all scenarios, 2050 target

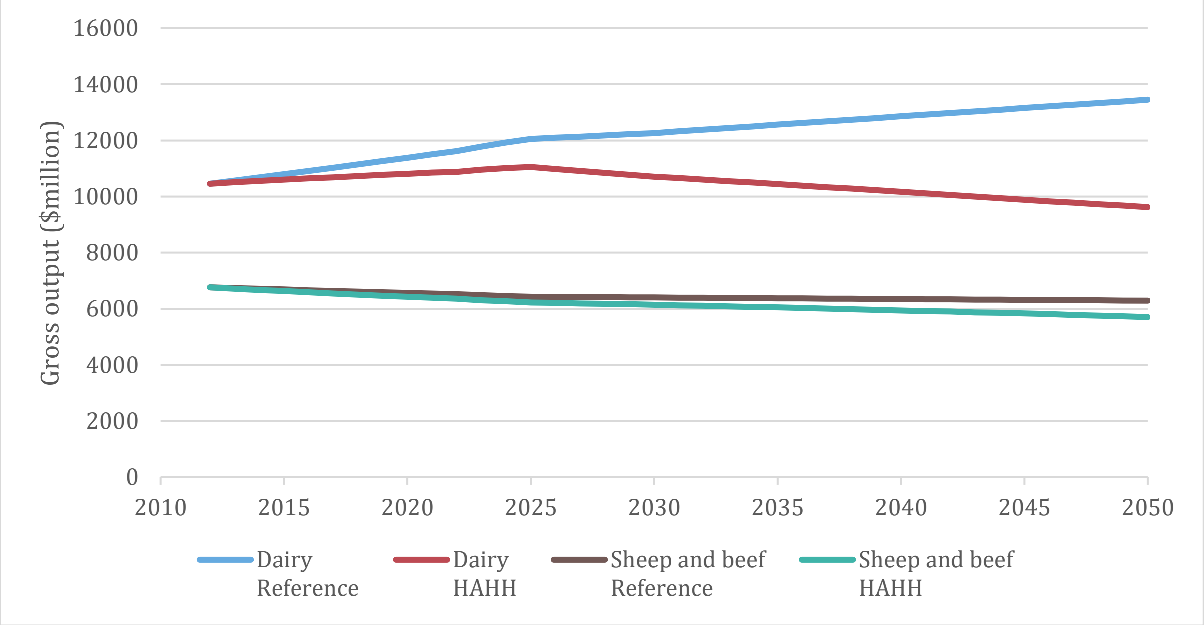


Note: Forestry land use in the HAHH and HAMit scenarios approximately coincide.

4.2.3 Changes in production and employment

LURNZ directly simulates changes in land use intensity depending on changes in land use areas and the location of those changes.

Figure 7. Dairy and sheep and beef production in the reference case and HAHH scenarios (2050 target)



Note: the series are generated by assuming that the percentage changes in production relative to their 2013 levels match that of intensity (in tonnes of milk solids for dairy and in thousands of stock units for sheep and beef) relative to the 2013 reference case level.

We then use ratios provided by Statistics NZ to give an indication of the likely shifts in direct land-based employment associated with changes in levels of production (dairy and sheep-beef) and land use (forestry and horticulture). Of course, there are also effects on processing industries as determined by inter-industry linkages.

Table 7 Employment relative to production and land use[27]

	Million $	FTE	Area (Mil ha)	FTE/mil$	FTE/1,000ha
Sheep &Beef	$6,738	43,550	8.15	6.46	5.3
Dairy	$10,567	44,800	2.10	4.24	21.3
Horticulture	$3,185	22,000	0.47	6.91	46.8
Forestry	$3,648	6,300	2.00	1.73	3.2

Overall it appears that the issue is not about total employment but rather a training, retraining, and education issue. The number of jobs falls in the sheep-beef sector, but in all scenarios except 2030 HA this is more than compensated for by rises in employment in dairy,

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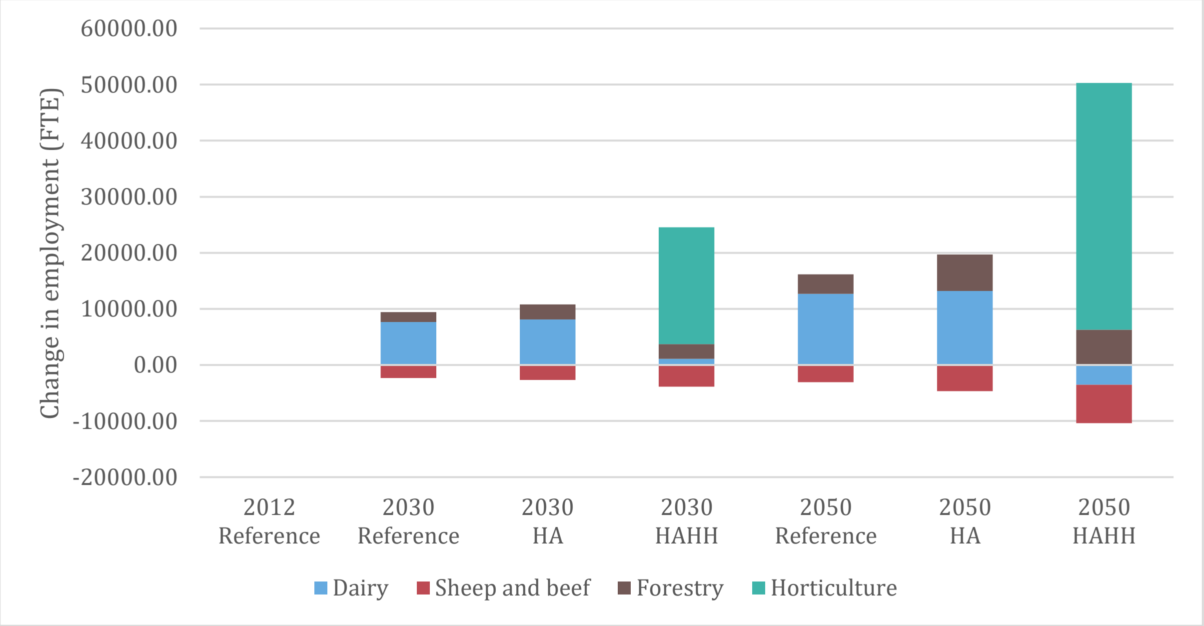
[27] The information on employment and gross output was provided by Adolf Stroombergen for the year ended March 2013. Data in 2012/13 dollars. Infometrics commissioned Statistics NZ to produce a fairly detailed table of employment by industry and hours worked from the 2013 census and then calculated full-time equivalents (FTE).

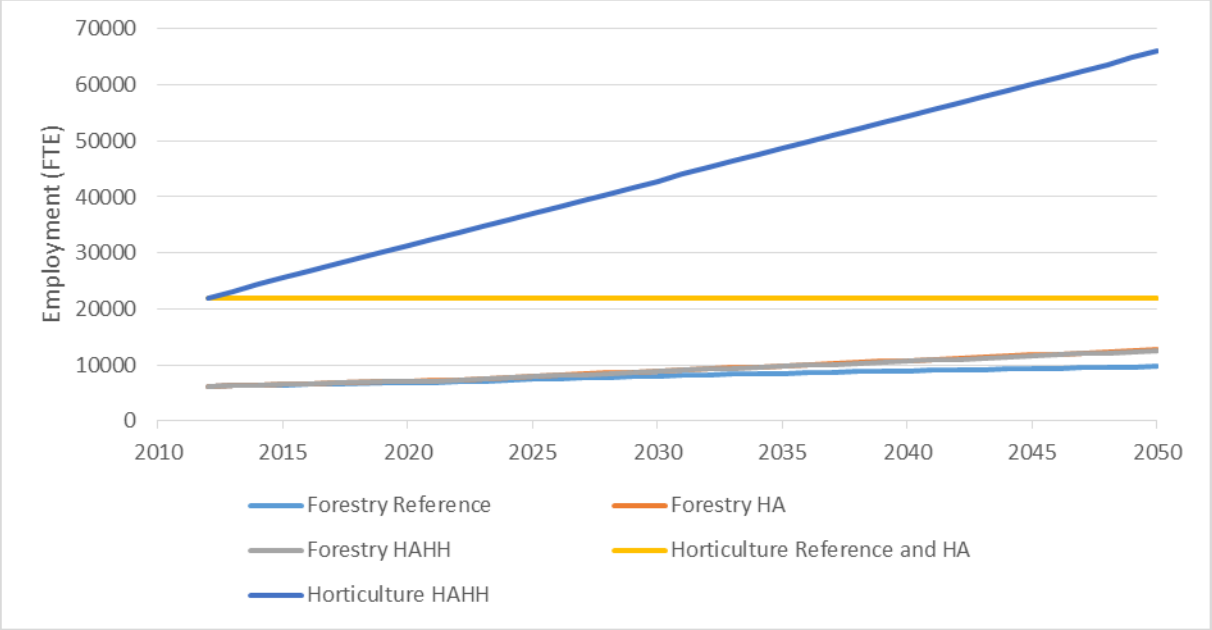
forestry and horticulture. If horticulture expands considerably, the effect on employment is significantly positive.

Figure 8. Change in employment relative to 2012 level in the reference case, HA, and HAHH scenarios



Note: the level changes are generated by assuming that the percentage changes in employment relative to their 2013 levels match those of production and land use relative to the 2013 reference case levels.

Figure 9. Forestry and horticultural employment in the reference, HA, and HAHH scenarios, 2050 target



Note: the series are generated by assuming that the percentage change in employment relative to the 2013 level matches that of land use relative to the 2013 reference case level. The forestry employment series in the HA and HAHH scenarios approximately coincide.

4.2.4 Emissions

The total net additional emissions paths for the reference case, high-ambition and high-ambition, high-horticulture scenarios are shown in Figure 10. These emissions are not the same as New Zealand's inventory for the land sector, in part because they exclude sequestration and emissions from all pre-2012 forests. After 21 years the first post-2012 forests reach their average long-term carbon stock. Further sequestration in these forests will be offset by later emissions from harvesting unless they become permanent forests. Sequestration in new forests gradually stabilises and eventually cannot offset rising dairy emissions. Emissions start rising again in the mid-2040s. This signals the significant challenges New Zealand will face in meeting targets after 2050 if most net mitigation in the land-use sector is driven by expansion in rotation forestry.

Figure 10. Net additional land-sector emissions across all scenarios, (2050 target) compared to all targets

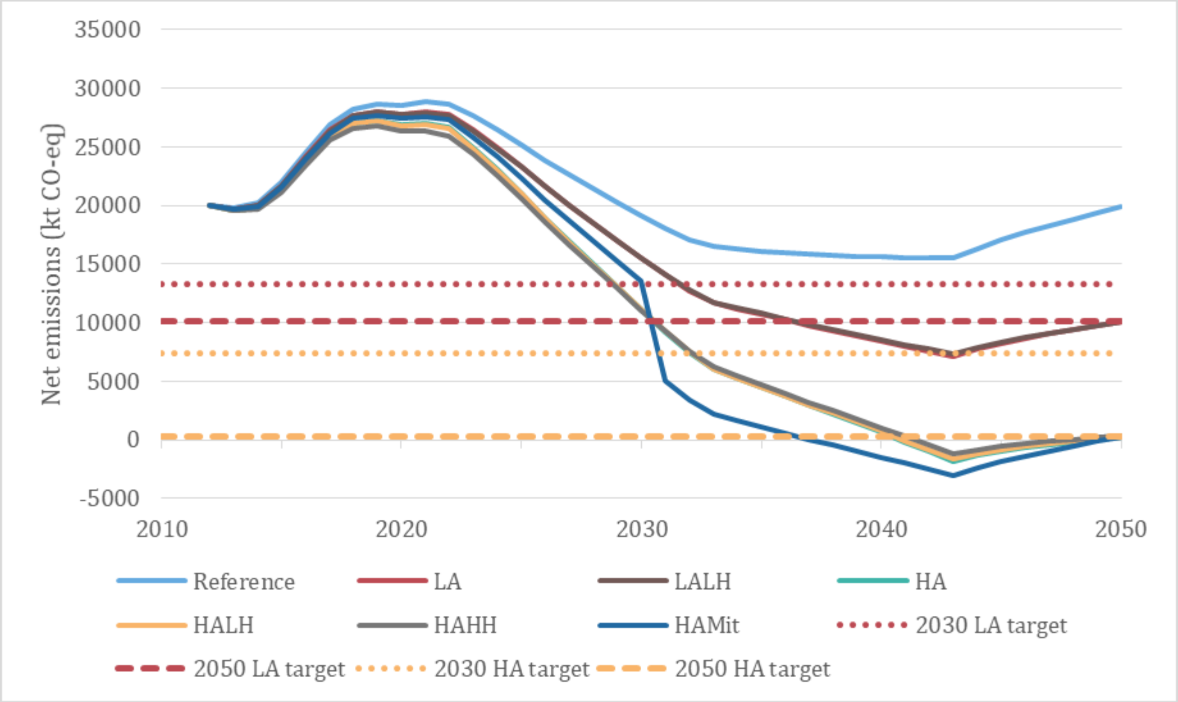
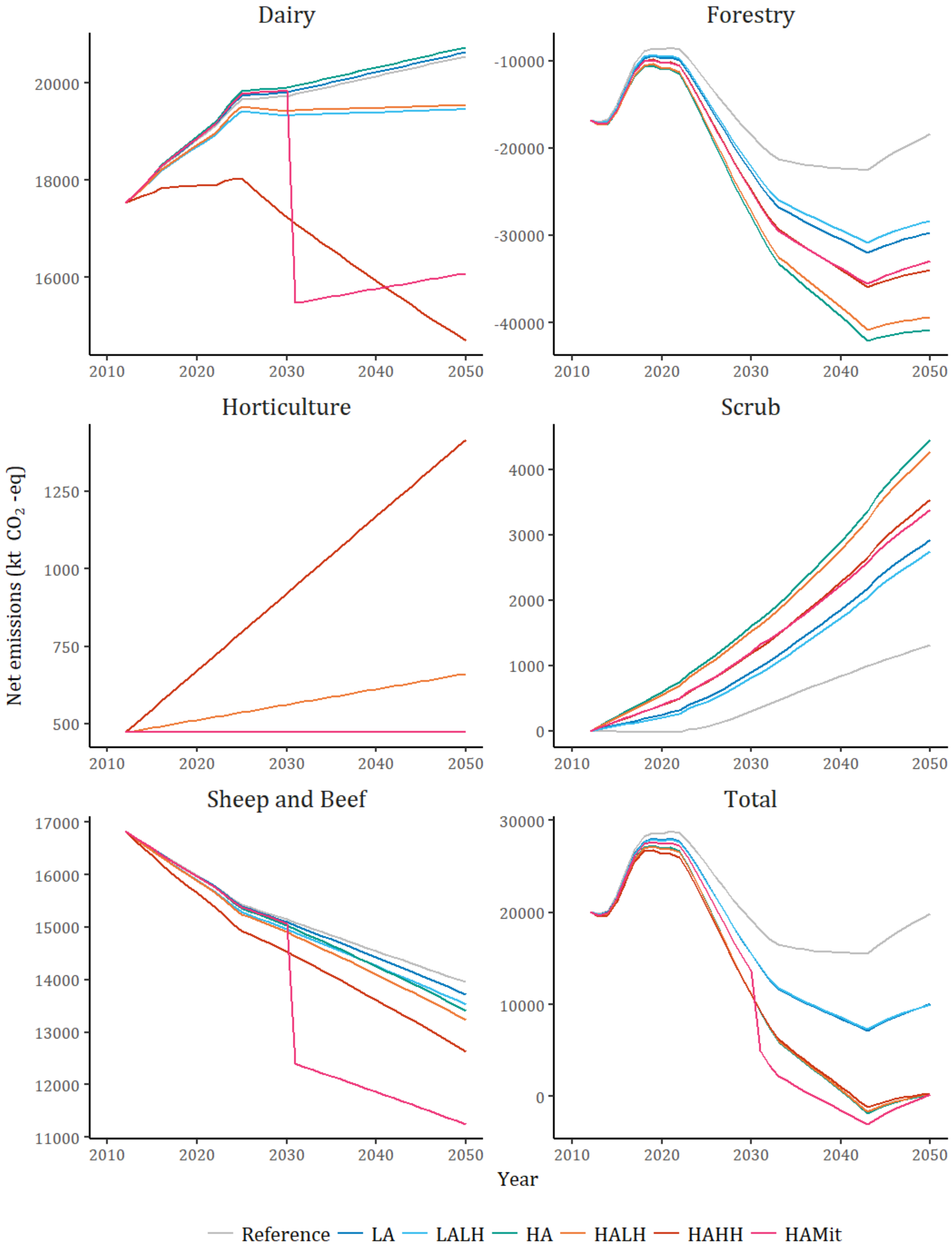


Figure 11. Net emissions across all scenarios by sector, 2050 target



In scenarios with no horticultural expansion, emissions from the dairy sector continue to rise, albeit at a lower rate. Only in the high-ambition scenario with high horticulture do emissions fall and even then, only after dairy conversions cease.

The introduction of the mitigation technology in 2030 has a dramatic effect on this sector. In reality it would probably be picked up gradually. Initially emissions drop even below the high-horticulture scenario but by 2050, when the horticultural expansion is fully implemented, it has a larger effect. If both were implemented, the effects would not be additive, but the joint impact would be much greater.

For sheep and beef emissions, as scenarios lead landowners to convert more land to other uses emissions fall. The larger horticultural expansion leads to a disproportionate reduction in emissions relative to the other changes. This is possibly because horticultural expansion occurs on areas of good-quality land that is currently used for intensive sheep and beef farming.

Interestingly, although forestry land use is driven almost entirely by the level of ambition, small reductions in forestry area growth, as a result of the lower emissions prices caused by horticultural expansion, produce more noticeable differences in emissions over time. This is particularly noticeable for the high-horticulture scenario.

Scrub emissions show essentially the inverse pattern to forestry emissions, but the emissions do not reverse as plantation forests begin to be harvested. This contributes to the increase in net land-sector emissions that begins in the mid-2040s.

4.3 Mitigation scenario results from NZFARM

The estimated responses to the 2030 and 2050 GHG-emissions reduction targets using the NZFARM model are outlined in this section. Because NZFARM is not a dynamic model, achieving the 2050 target is independent of the cost of achieving the 2030 target. This means that the scenario results should be compared against the reference case for the relevant year (2030 or 2050) and not between 2030 and 2050.

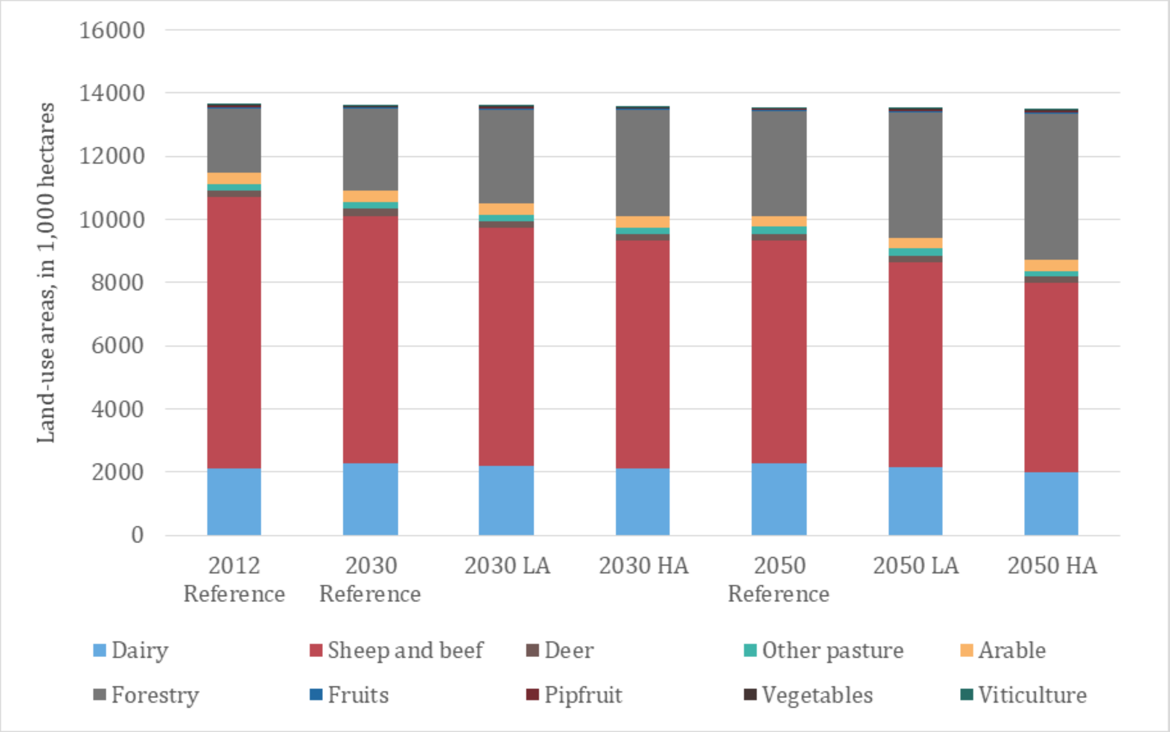
4.3.1 Land-use

The largest decrease in land-use area in the low- and high-ambition scenarios modelled with NZFARM for 2030 and 2050 (shown in Figure 12); see also results on relative change of land uses in Table 21 in Appendix E: Detailed results) is sheep and beef followed by dairy. Other pasture and deer have relatively large percentage changes in area but have small areas in comparison to sheep and beef and deer. Compared to the reference case, the area in sheep and beef in 2050 decreases by 15% (i.e. approximately one million hectares) in the high-ambition scenario. In the low-ambition scenario, the sheep and beef area reduces by 7% (i.e. about 0.5 million hectares) by 2050. Dairy area by 2050 for the low-ambition scenario decreases by 7% (i.e. about 160 thousand hectares) and by 14% (i.e. about 317 thousand hectares) for the high-ambition scenario.

Forestry area in both the low- and high-ambition scenarios has the largest increase in area. In the low-ambition scenario, forestry area increases by 15% in 2030 and by 20% in 2050 compared with the reference case areas of 2,6 million ha in 2030and 3.3 million ha in 2050. The increases in forestry area for the high-ambition scenarios are 30% in 2030 and 39% in

2050. The area of vegetables, arable crops, and fruit, which are determined endogenously in NZFARM, also increase due to the lower GHG emissions from these land uses compared to pastoral land uses and high profits (i.e. EBIT).

Figure 12. Land-use areas in the reference, low ambition endogenous horticulture (LAEH), and high ambition endogenous horticulture (HAEH) scenarios in 2012, 2030, and 2050



4.3.2 Profits

The baseline for 2012 shows that dairy and sheep and beef earn the highest shares of income, representing 30% and 32% respectively, of the total net agricultural revenue in New Zealand. This is equivalent to about $8.9 billion (Figure 13; see also results on relative change of profits in Table 22 in Appendix E: Detailed results).

The reference case shows increases in profit for dairy and forestry and a decrease in profit for sheep and beef. This is driven by the projected increase in area of dairy and forestry land uses and a decrease in sheep and beef area (see Figure 12) in the reference case between 2030 and 2050. Although the total profits of dairy and sheep and beef are similar, the per-hectare revenues are different – the average profits per hectare for dairy is $1,599 and for sheep and beef is $326.[28]

The low- and high-ambition scenarios in 2030 and 2050 show a reduction in profit from pastoral land uses (dairy, sheep and beef, deer, and other pasture). The largest decrease in

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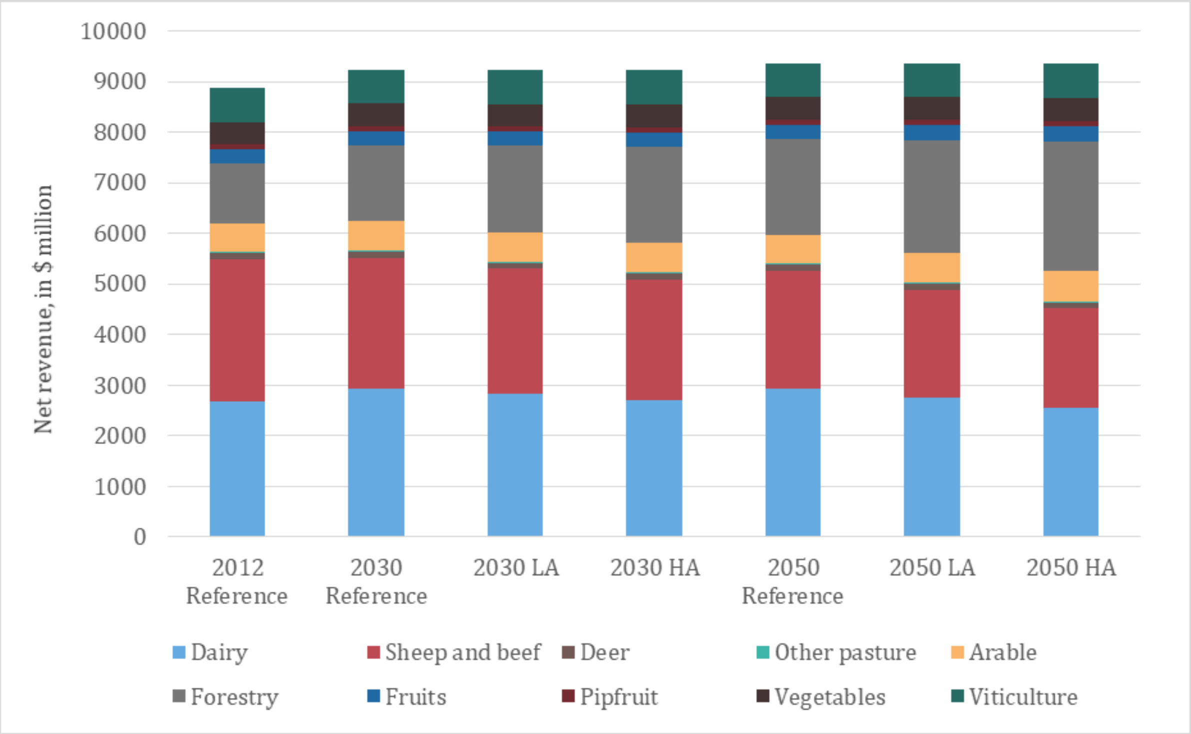
[28] The dairy profit data is from Dairy NZ for 2017; sheep and beef profits are from Beef and Lamb New Zealand from 2015.

profit is from the dairy and sheep and beef land uses in the high-ambition scenario. This corresponds to the large reduction in area for these land uses compared to the reference case. Despite a decrease in profit from pastoral land uses, the total profit from agriculture and forestry does not change substantially. In the high-ambition scenario, the change in profit across all land uses is about 0.2% lower than the reference case in 2050. The increased forestry area and its profit mitigate the decreased profit from pastoral land uses.[29] Profits from arable, fruit, vegetables, and viticulture also increase but to a lesser extent than forestry. The average profit from horticultural land uses is $10,173 per hectare but the model predicts a negligible increase in area of these crops in comparison to the increase in forestry area.[30]

Figure 13. Profit in the reference, low(LAEH)-, and high(HAEH)- ambition scenarios in 2012, 2030, and 2050.



4.3.3 GHG emissions

GHG emissions levels from agriculture are substantial; the largest emissions are from dairy (average emissions are 9.1 t CO_2-e per ha) and sheep and beef (average emissions are 2.9 t CO_2-e per ha) followed by other pastoral land uses (Figure 14; see also results on relative change of GHG emissions in Table 23: in Appendix E: Detailed results). Therefore, pastoral land uses, particularly dairy and sheep and beef, are most affected by the GHG targets in the low- and high-ambition scenarios. GHG emissions from deer and other pastoral land uses also decrease,

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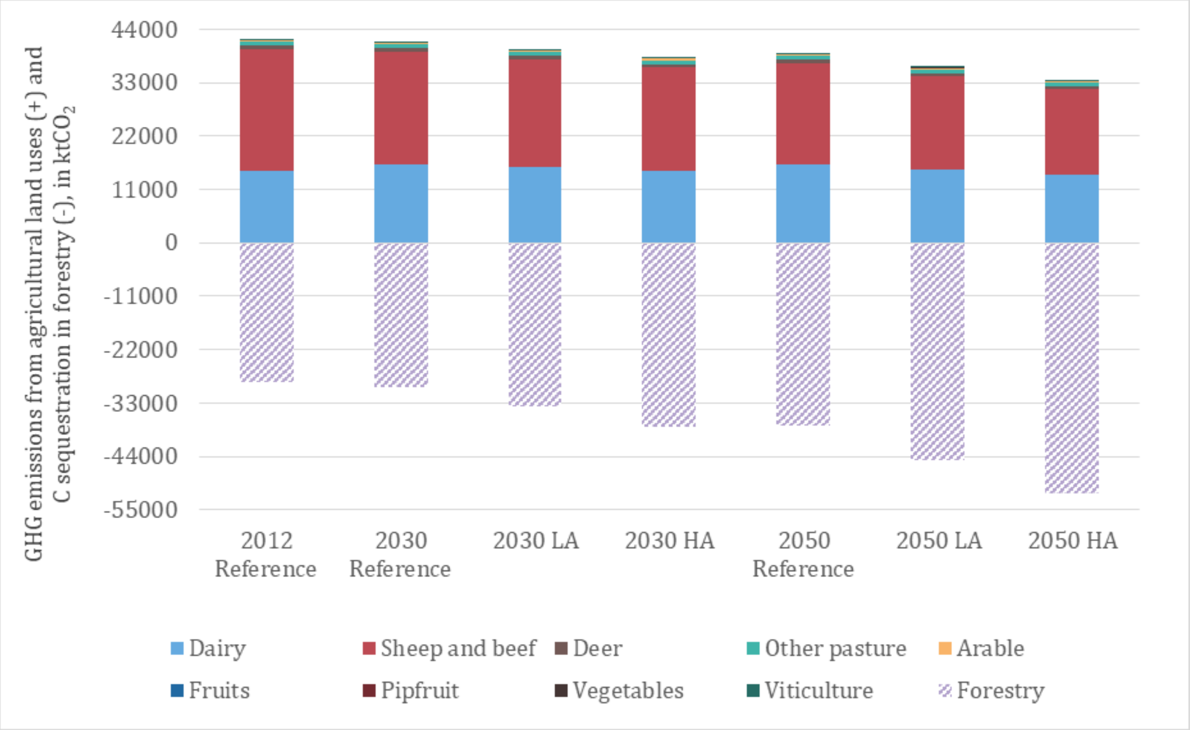
[29] NZFARM assumes annualised profits from forestry of $521 per ha.

[30] Profit data obtained from Horticulture New Zealand for the 2015-16 year.

but because of their relatively small area, the absolute emissions reductions from these land uses are small. The increased area of arable crops, fruit, and vegetables, however, results in a small absolute increase in GHG emissions in the low- and high-ambition scenarios compared with the reference case.

Figure 14. Land-use GHG emissions and C sequestration in the reference, low(LAEH)-, and high(HAEH)-ambition scenarios in 2012, 2030, and 2050

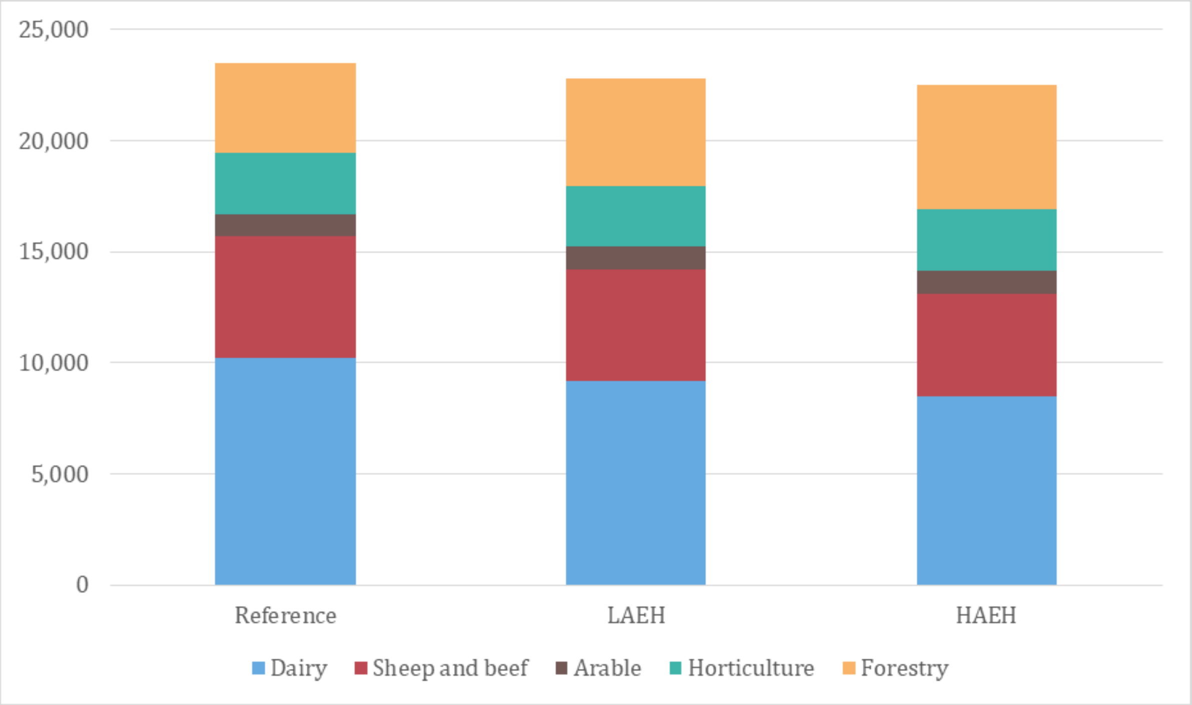


The total C sequestration from forestry (average sequestration is 11 t CO_2-e per ha) increases over time in the reference case due to the increase in forestry area (see Table 24 in Appendix E). Low- and high-ambition scenarios further enhance the C sequestration in forestry. C sequestration in forestry increases almost by fourfold in the high-ambition scenario in comparison to the sequestration levels in the 2012 baseline.

4.3.4 Gross output of agriculture and forestry

Figure 15 shows a fall in gross output from dairy, and sheep and beef, relative to the reference case. In contrast, gross output from forestry increases substantially and from horticulture and arable gross output increases slightly. These effects strengthen with ambition. More details are given in Table 25 in the Appendices.

Figure 15: Gross output of agriculture and forestry in the reference, low(LAEH)-, and high(HAEH)-ambition scenarios in 2050 ($ million)



4.4 Comparison of LURNZ and NZFARM results

4.4.1 Comparison of land-use projections between LURNZ and NZFARM

This section compares the results from LURNZ and NZFARM. The models differ in how some land uses are treated, in how the models are structured and parameterised, and in how the GHG emissions are estimated. For instance, in NZFARM the area of horticulture and arable crops increase with increasing GHG targets, although there is negligible change in their overall area, compared to LURNZ where horticultural area is exogenously determined. It thus makes most sense to compare the NZFARM scenarios to the LURNZ scenarios with no horticultural expansion.

The key difference in the results is that the forestry response to the GHG reduction targets is higher in NZFARM than in LURNZ. This is almost certainly driven by the different way that forestry sequestration is modelled. LURNZ mimics the new averaging approach used by the Ministry for the Environment and assumes each hectare of additional forest sequesters 31.83 tonnes per year for 21 years (then nothing more); NZFARM in contrast assumes that all forest sequesters 10.9 tonnes ha on average.[31] Therefore to achieve a given additional mitigation target in the short term, NZFARM requires a larger forest area than LURNZ. These differences in forestry response largely drive the differences in scrub and sheep-beef land. The

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[31] This is total sequestration net of emissions from decay of harvest residues.

dairy area in NZFARM also declines with the more stringent GHG emissions target, while in LURNZ only horticulture can compete with dairy, so dairy area is almost unchanged.

Table 8. Land-use projections in the LA and HA scenarios using LURNZ and NZFARM

Land-use Category	Year	Area (millions of hectares)					
		Reference	LA	HA	Reference	LA	HA
		LURNZ	LURNZ	LURNZ	NZFARM	NZFARM	NZFARM
Dairy	2012	2.10			2.10		
	2030	2.30	2.31	2.32	2.30	2.20	2.11
	2050	2.30	2.31	2.32	2.30	2.14	1.98
Sheep and beef	2012	8.15			8.6		
	2030	7.43	7.38	7.32	7.82	7.52	7.22
	2050	7.05	6.81	6.54	7.03	6.52	6.01
Forestry	2012	2.00			2.05		
	2030	2.57	2.70	2.86	2.59	2.98	3.37
	2050	3.11	3.59	4.08	3.32	3.97	4.63
Horti-culture	2012	0.47			0.133		
	2030	0.47	0.47	0.47	0.133	0.134	0.135
	2050	0.47	0.47	0.47	0.133	0.135	0.136

Notes: Table 18 details how NZFARM land-use categories are aggregated with the LURNZ model. The latter considers effective and non-effective land, whereas NZFARM includes only effective land. The displayed NZFARM projections are converted to total (effective plus non-effective) land by assuming that the ratio of effective to total land in 2012 is constant across time for all land uses and all scenarios.

5 General equilibrium effects of changes in land-use sector production and model comparisons

To explore these land-use change effects on the economy in an alternative way, Adolf Stroombergen used the ESSAM Computable General Equilibrium model. The model was 'shocked' by shifting international demand for outputs from each sector so that New Zealand would then produce and sell more or less of each. The changes in production levels from each sector, for each scenario, were those produced in the LURNZ model scenarios (see Table 11). The model then allows the economy to respond to the shifts in demand for inputs to each sector, and to changes in employment and incomes and hence consumption and produces estimates of changes in macroeconomic indicators relative to the reference scenario.

Assumptions about all other aspects of the economy are held constant, including the emissions price. The model closure assumptions are given in Appendix C.

5.1 Scenarios to 2050

Three scenarios to 2050 are analysed:

1. High ambition for land sector emissions (HA)
2. High ambition with low increase in horticulture (HALH)
3. High ambition with high horticulture (HAHH)

As we are interested in the economy-wide effects of changes in land use relative to the reference case, unconfounded by the effects of a change in the price of emissions on the rest of the economy, that price is kept constant. This implies that the forestry industry is subject to a higher emissions price than the rest of the economy, which in practice is unlikely to be efficient. In the reference case the price of emissions in 2050 is $44/tonne of CO_2-e, increasing to $72/tonne in the HAHH scenario.

We simulate the changes in land use as exogenous shifts in world demand for New Zealand exports, notably less meat, fewer dairy products, more horticulture (including fruit, viticulture, and crops) and more logs coupled with a small increase in wood products. We do not allow for a macroeconomic effect from the policies that lead to these land-use changes. These policies may impose some economic costs to the economy as well as leading to some redistribution. We also exclude the benefits to New Zealand from lower emissions from the land sectors lowering the overall cost to New Zealand of meeting international targets – for example reducing any need to fund international mitigation.

5.2 Macroeconomic results

The main macroeconomic results are shown in

Table 9. In the HA scenario gross domestic product (GDP) is 0.6% higher than in the reference case, rising to 0.8% in the HALH scenario and 1.3% in the HAHH scenario. In the HA scenario, value added in the land sector rises by a total of 5.6% (see Table 26 in the Appendices); this constitutes around 30% of the overall increase in GDP. In all cases the increase in real gross national disposable income (RGNDI) is more than the increase in GDP – up to double the amount in the HAHH scenario.

The increases in RGNDI are pushed along by the improvements in the terms of trade that are associated with the assumed changes in world demand. Higher terms of trade also means that more resources can flow into the production of goods and services for household consumption, rather than being used to produce exports. In the HAHH scenario Private consumption increases by 3.4% over the Reference case compared to 2.3% for exports.

The importance of the terms of trade effect is worth emphasising. Essentially the model has been told that the world desires more of New Zealand's logs, fruit, and vegetables. In the HAHH scenario demand for horticultural products is assumed to triple relative to the reference case.[32] Simultaneously the demand for dairy and meat (and by implication also wool) declines relative to the reference case. This assumed switch in demand is paramount. Simply changing the amount of land allocated to each use would not produce the observed favourable macroeconomic effects. There must be a market for the new mix of products at prices that make them profitable to produce.

Table 9. Macroeconomic results for 2050 (change on reference case)

	HA		**HALH**		**HAHH**	
	% Δ on Reference		**% Δ on Reference**		**% Δ on Reference**	
Private consumption		1.2%		1.8%		3.4%
Exports		0.6%		1.1%		2.3%
Imports		2.0%		3.2%		6.9%
GDP		0.6%		0.8%		1.3%
RGNDI[33]		1.0%		1.4%		2.6%
Terms of trade		1.3%		2.1%		4.5%
Real wage rate		1.1%		1.8%		3.8%
	CO_2-e (Mt)		**CO_2-e (Mt)**		**CO_2-e (Mt)**	
Gross emissions	78.4	-0.1%	77.2	-1.6%	73.2	-6.7%
Forestry emissions	-36.3		-35.1		-30.4	
Net emissions	42.1	- 31.5%	42.1	- 31.5%	42.8	-30.3%
Agricultural CH_4 & N_2O	36.4	-0.8%	35.0	-4.7%	30.4	-17.4%

5.3 Emissions

The model indicates that gross emissions are flat in the HA scenario but fall by 1.6% and 6.7% in the HALH and HAHH scenarios respectively, due to the change in the composition of agriculture *and* the associated flow-on effects. In scenario HAHH the change in agricultural emissions of 17.4% corresponds to 6.4 megatonnes, while the change in total gross emissions

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[32] ESSAM uses Statistics New Zealand definitions of sectors so 'horticulture' does not include arable.

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

is 5.3 megatonnes, so approximately 17% of the reduction in emissions from agriculture is "lost" to increased activity elsewhere in the economy.

The difference in emissions absorption by forestry between HALH and HAHH is almost exactly offset by the difference in agricultural emissions (both being 4.7 Mt). Therefore the overall change in net emissions of 0.7 megatonnes is accounted for by the increase in economic activity in the rest of the economy.

5.3.1 Comparison of emissions results: LURNZ, NZFARM and ESSAM

The reduction in net emissions is almost identical between NZFARM and LURNZ (by design). The emissions reductions in NZFARM are driven more by reductions in methane and nitrous oxide and less by forestry sequestration, than those in LURNZ, although neither model projects large changes in biological emissions in the high ambition scenario where land-use change is driven only by changes in profit. The difference is probably mostly a result of different emission factors in the two models. ESSAM is comparable to LURNZ (and shares the same Reference case) but not to NZFARM. The difference between ESSAM and LURNZ biological emissions in the High Ambition scenario arises from general equilibrium effects that lead to second order shifts in land use and production.

Table 10. Emissions from the land sector in 2050 in the reference and HA scenarios using LURNZ, NZFARM and ESSAM (CO2-e)

Model & Scenario		Forestry and scrub sequestration	CH_4 and N_2O	Net emissions
LURNZ				
	Reference	-17,039	36,931	19,891
	HA	-36,343	36,573	230
NZFARM				
	Reference	-37,638	40,667	3,029
	HAEH	-51,562	35,034	-16,528
ESSAM				
	Reference	-17,039	36,931	19,891
	HA	-36,343	36,400	143

Notes: Accumulated rounding errors in HA scenario net emissions projections lead to variation in the difference between the reference case and HA scenario projections across models.

5.4 Effects on agriculture and forestry output, value added and employment

The effects on gross output and employment in the model's four agricultural industries and the forestry industry are shown in Tables 12 and 13. In the HAHH scenario horticulture expands by 212%, while sheep and beef and dairy decline by 13% and 28% respectively. For the HALH scenario the changes are smaller as the shift to more horticulture is less marked (by assumption). In the HA scenario the shifts are smaller still. There is no exogenous shift in the demand curve for horticultural exports in this scenario, so the industry's output is entirely endogenous.

Note that these changes are not exactly as documented in the LURNZ modelling. There is little point in attempting exact calibration between the output of a partial equilibrium model (such as LURNZ) and the output of a general equilibrium model. Perfect output calibration completely eliminates any feedback effects from the wider economy that might occur, which is precisely why a general equilibrium analysis is undertaken.[34]

The changes in employment are generally close to but slightly less than the changes in output, implying a marginal shift to greater capital intensity. Total employment is held constant at the reference case level (see Appendix C). Changes in output and capital-labour substitution could be different at the regional level, but our model has no spatial dimension.

Total employment in the four agricultural sectors in the reference case is 86,500 FTE, increasing to 136,900 FTE in the HAHH scenario. Employment losses in pastoral agriculture are more than offset by the expansion in horticulture. The HALH scenario also has an increase in agricultural employment relative to the reference case, while in the HA scenario agricultural employment is virtually unchanged.

Table 11. Gross output in agriculture and forestry 2050 (change on reference case)

	HA	**HALH**	**HAHH**
		% Δ on Reference	
Horticulture	6%	59%	212%
Sheep & beef farming	-3%	-7%	-13%
Dairy farming	1%	-5%	-28%
Other farming	2%	12%	42%
Forestry	22%	21%	16%
Total	6%	17%	41%

Value added shifts slightly more than gross output. In the HA scenarios, the effect of the general equilibrium shifts on value added is positive, leading to an overall gain in the sector of 5.6% as opposed to a 4.4% direct effect. The effect of changes in value added within the land sector contributes roughly 30% of the overall increase in New Zealand's GDP.

These results are not directly comparable to those from NZFARM, in part because the latter are only partial equilibrium, but also because ESSAM uses the LURNZ scenarios which have less of a land-use shift toward forestry than those in NZFARM. The difference in land-use projections probably explains the different effects in forestry and sheep and beef farming, but does not explain the different outcomes for the dairy sector.

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[34] There may also be small differences in industry definitions.

Table 12 Comparison of value added and Profits: ESSAM and NZFARM

	ESSAM: HA	**NZFARM: HAEH**
	% Δ on Reference	
	Value add	Profit
Horticulture	6.7%	2.5%
Sheep & beef farming	-3.3%	-15%
Dairy farming	0.9%	-13%
Other farming	2.5%	1.3%
Forestry	22.3%	35%
Total	5.6	-0.2%

The big differences here are probably driven by the very different land use outcomes. In NZFARM forestry expands much more, and pastoral agriculture contracts much more, than in the LURNZ results that are used for the ESSAM modelling.

Table 13. Employment in agriculture and forestry 2050 (change on reference case): ESSAM and LURNZ

		ESSAM		**LURNZ**	
	HA	**HALH**	**HAHH**	**HA**	**HAHH**
			% Δ on Reference		
Horticulture	6%	57%	206%	0%	200%
Sheep & beef farming	-4%	-8%	-15%	-4%	-9%
Dairy farming	0%	-6%	-29%	1%	-29%
Other farming	2%	11%	38%	-	-
Forestry	22%	21%	14%	31%	29%
Total	4%	17%	53%	2%	19%

5.5 HAMit scenario to 2050

The HAMit scenario assumes that a vaccine or similar mitigation technology exists that reduces livestock emissions by 30% in dairy farming (or 22% of total biological dairy emissions) and by 20% in sheep and beef farming (17% of biological emissions).

5.5.1 Macroeconomic results

The macroeconomic results for the HA and HAMit scenarios are shown in Table 14.

Table 14. Macroeconomic results for 2050 (change on reference case)

	HA		**HAMit**	
	% Δ on Reference		**% Δ on Reference**	
Private consumption		1.2%		0.5%
Exports		0.6%		0.2%
Imports		2.0%		0.6%
GDP		0.6%		0.2%
RGNDI[35]		1.0%		0.3%
Terms of trade		1.3%		0.4%
Real wage rate		1.1%		0.4%
	CO$_2$-e (Mt)		**CO$_2$-e (Mt)**	
Gross emissions	78.4	-0.1%	73.0	-6.9%
Forestry emissions	-36.3		-29.5	
Net emissions	42.1	-31.5%	43.5	-29.1%
Agricultural CH_4 & N_2O	36.4	-0.8%	31.2	-15.0%

The HAMit scenario has smaller economic impacts than the HA scenario, implying that the general economy benefits more from an increase in forestry together with less output from sheep and beef than from a technology that lowers agricultural emissions and has less of a land shift to forestry. However, the way that the HAMit scenario is currently defined means that the economic effects could be understated. As agricultural methane emissions are not priced, there is no effect on agricultural output prices. Also, without an explicit national emissions target (gross or net), there is no national value attributed to lower emissions from agriculture and no effect on the emissions price in the rest of economy needed to achieve such a target. In other words, the benefits of a methane vaccine or equivalent mitigation technology would be more apparent in the context of an emissions target.

If, for example, the difference in total emissions between the reference case and the HAMit scenario could be sold overseas at the reference case price of $44/tonne that would generate foreign exchange earnings of about $240 million.

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[35] Real gross national disposable income is GDP adjusted for net offshore factor payments (such as interest and dividend flows) and for changes in the terms of trade.

5.5.2 Emissions

The reduction in net emissions is not much different in the two scenarios (by design), with the effects of the mitigation technology on agricultural emissions being more than offset by the lower emissions absorption in forestry. The similar net emissions results, but different macroeconomic effects, simply indicate that some approaches to achieving a given target will be more economically costly than others. In this specific case, the relative attractiveness of the approach without the mitigation technology depends almost entirely on an assumption that we will be able to expand our export markets for products from low emission land uses and our production of those products with current levels of profitability..

5.5.3 Effects on agriculture and forestry

The effects on gross output and employment in the model's four agricultural industries and the forestry industry are shown in Table 15. In both scenarios horticulture is endogenous, but whereas in the HA scenario the industry expands by 6%, in the HAMit scenario it is virtually unchanged, relative to the reference case. With less of a reduction in pastoral agriculture, fewer resources (not just land) are freed up to shift into other industries.

Table 15. Gross output and employment in agriculture and forestry 2050 (change on reference case)

	HA		**HAMit**	
	Output	**Employment**	**Output**	**Employment**
		% Δ on Reference		
Horticulture	6%	6%	-1%	-1%
Sheep-beef farming	-3%	-4%	0%	-1%
Dairy farming	1%	0%	0%	0%
Other farming	2%	2%	0%	-1%
Forestry	22%	22%	16%	16%
Total	6%	4%	3%	1%

6 Key results, barriers to effective response, and social implications

This work aims to better understand what land-use transitions in New Zealand will need to happen if the country aims to reduce its land-based GHG emissions as specified in our imposed targets. Reduced emissions were considered in net terms, as forestry sequestration plays an important role in reducing CO_2 in the atmosphere.

To impose a net reduction of GHG emissions from land-based sectors, we considered the gross emissions from agriculture in year 2005. Thus, two main sets of scenarios were analysed: a net reduction of 30% (by 2030) and 50% (by 2050) of the gross 2005 agricultural emissions;

and a net reduction of 15% (by 2030) and 25% (by 2050) of the gross 2005 agricultural emissions, both in addition to the levels to be achieved following a "business as usual scenario" – defined as the "reference case scenario" in this report.

We focus on the results to meet the 2050 targets and specifically those to meet the high-ambition 2050 target. The 2030 target is harder to achieve; the low-ambition scenario is obviously easier. Results across the years and ambition are qualitatively similar.

6.1 Key results

Both models show a large increase in forestry is needed to meet the targets in all scenarios (LURNZ requires an average of 58,000 ha per year of new planting in the high-ambition scenario or 29,000 more per year than in the reference case). In the LURNZ scenarios the increase in forest area is lowered significantly where there is a large expansion in horticulture or a new technology such as a methane vaccine becomes available.

Scrub decreases in the high-ambition scenario as roughly half of new planted forest area will come from scrub. The historic decline in sheep-beef land continues but at a slightly higher rate relative to the period 2002–12 (17% relative to 13% in the high ambition scenario).

The dairy area declines relative to the reference case in NZFARM with some conversion to horticulture and forestry. In LURNZ the dairy area is reduced only by conversion to horticulture in the high-horticulture scenarios.

After 21 years, the first post-2012 forests reach their average long-term carbon stock. Further sequestration in these forests will be offset by later emissions from harvesting unless they become permanent forests. Sequestration in new forests gradually stabilises and eventually cannot offset rising dairy emissions. Emissions start rising again in the mid-2040s. New Zealand will therefore face significant challenges in meeting targets after 2050 if most net mitigation in the land-use sector is driven by expansion in rotation forestry.

In scenarios with no horticultural expansion, emissions from the dairy sector continue to rise, albeit at a lower rate. Only in the high-ambition scenario with high horticulture do emissions fall and, even then, only after dairy conversions cease.

An on-farm mitigation breakthrough (methane vaccine or equivalent on-farm technology or practice change) has roughly the same effect on emissions prices and the area in forestry/scrub as the scenario where horticultural area increases by one million hectares. The required implicit emissions price in 2018, for the high-ambition scenario that meets the 2050 target, falls from around $63 to $50.

In the high-ambition scenario the computable general equilibrium (CGE) analysis suggests that gross domestic product (GDP) is 0.6% higher than in the reference case, rising to 0.8% in the high-ambition, low-horticulture scenario and 1.3% in the high-ambition, high-horticulture scenario. In all cases the increase in real gross national disposable income

(RGNDI) is more than the increase in GDP – up to double the amount in the high-ambition, high-horticulture scenario. The increases in RGNDI are pushed along by the improvements in the terms of trade. In the high-ambition, high-horticulture scenario private consumption increases by 3.4% over the reference case compared to 2.3% for exports. However, there must be a market for the new mix of products at prices that make them profitable to produce. Significant changes in training and local infrastructure are also required to enable large shifts toward horticulture. In the NZFARM modelling the emissions reduction targets are achieved in the land sector with a small cost to the national economy. Reduced emissions from the land sector will lower the cost of achieving New Zealand's Paris target to all other sectors because they will need to reduce less and/or the government will need to purchase fewer offshore units. In both the CGE and NZFARM analyses these positive macroeconomic effects are excluded.

In terms of gross output, in the high-ambition, high-horticulture scenario, horticulture expands by 212%, while sheep and beef and dairy decline by 13% and 28% respectively. For the high-ambition, low-horticulture scenario the changes are smaller, as the shift to more horticulture is less marked. In the high ambition scenario, the shifts are smaller still.

Total employment in the four agricultural sectors in the reference case is 86,500 FTE, increasing to 136,900 FTE in the high-ambition, high-horticulture scenario. Employment losses in pastoral agriculture are more than offset by the expansion in horticulture. The high-ambition, low-horticulture scenario also has an increase in agricultural employment relative to the reference case, while in the high-ambition scenario agricultural employment is virtually unchanged.

The modelling suggests that meeting the 2030 target would be feasible but challenging. Land-use change is slow, trees initially grow slowly, and no dramatic changes in the options for on-farm mitigation (i.e. without land-use change) are expected by 2030. The 2030 target is harder to achieve than the 2050 target but is still possible, even under the high-ambition scenario with no horticultural expansion. Within LURNZ the implicit emissions price required for the high-ambition scenario is higher for the 2030 target ($80 in 2018 for the 2030 target relative to $62 for the 2050 target). This is partially because the rate of emissions reduction required is much faster between 2018 and 2030 than between 2030 and 2050. Given that land-use change is gradual, a higher incentive is needed to achieve a high enough rate of forestry conversions to meet the 2030 target.

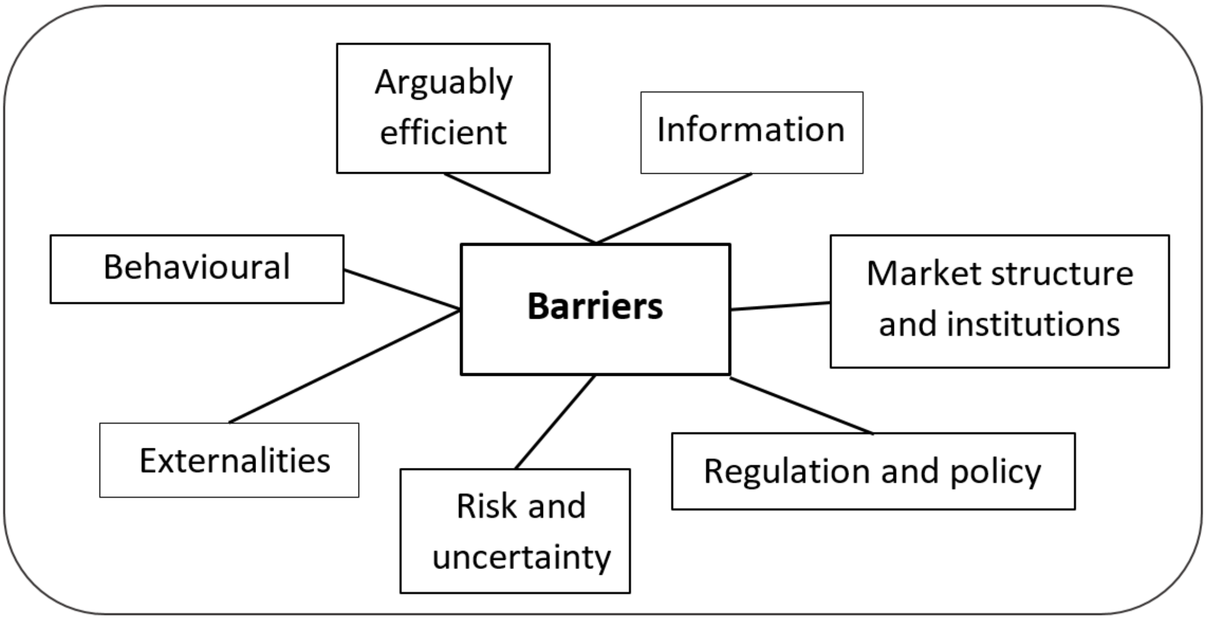
The land-use changes in the LURNZ scenarios are significant but have been experienced previously in New Zealand's history, with the exception of the assumed expansion of horticulture in some LURNZ scenarios. NZFARM scenario allows horticulture to expand endogenously and it expands very little. To achieve the level of expansion modelled in the LURNZ scenarios will likely require complementary policies. Are these land-use changes toward forestry and horticulture likely to occur in reality in response to climate policy? What would they be likely to mean for local economies and communities?

6.2 Non-price barriers to land-use change

Analysis of profitability might suggest that the optimal decision would be to change land use. Within a farm business, however, farm managers, operators, and even shareholders (owners) can face non-price reasons that deter change. These non-price reasons could be understood as "barriers" that decision makers might face when they decide whether to change the use of land within the farm. Most of these barriers are taken account of in the modelling because the models are parameterised based on actual farmer behaviour. Identifying and addressing them can potentially allow more rapid change than we have identified. A critical exception is that we assume that farmers will respond to policy in the same way that they respond to market forces.

Jaffe (2017) created a typology to identify and classify the factors other than expected profitability that can affect farmers' decisions. Based on economic theory, psychology, sociology, and empirical evidence found in the broader international literature focused on barriers to technology adoption, he identifies 27 different barriers that farmers (and other farm decision makers) could face. These can disincentivise land-use change or the adoption of new practices in agriculture. These 27 barriers can be categorised in seven different groups, which are shown in Figure 16.

Figure 16. Barriers to efficient decision making in farming contexts.[36]



The first "arguably efficient" group of barriers is where a financial profitability test fails to correctly measure the economic impact on the farmer. Alternative land uses suggested by an

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[36] Adapted from Jaffe (2017).

analyst may in fact impose important short- or long-term financial burdens on the farmer. Alternatively, the farmer may incorrectly perceive a negative financial benefit in practice when in reality it would be profitable.

"Informational" barriers occur in situations where adoption of land-use change (in our case) is not implemented because of imperfect availability of information. This type of barrier can explain, for instance, why even with high emissions prices, forestry might still not be attractive. For example, because of the complexity of the system or lack of confidence in future emissions prices despite strong cross-party commitment, the ETS might lead to lower rates of afforestation in the future relative to our forecasts.

"Market and institutional" barriers refer to failures in these areas that inhibit adoption. For example, a lack of training programmes focused on skills needed in the horticultural sector could slow its expansion. Poorly developed international market access or unreliable transport infrastructure could also inhibit development.

"Regulation and policy" barriers are those due to existing or potential constraints from public policy or the law. These two groups are generally external barriers to adoption in farming contexts, as they are not within the power of the farmer to change. For example, biosecurity regulations that unnecessarily delay introduction of a new crop or food safety regulations that don't develop fast enough to be applied to new products. Inflexible RMA regulations could also pose barriers – for example, by limiting horticulture's access to water.

"Risk and uncertainty" must be understood from the perspective of the farmer. For instance, as part of a project Motu is conducting to better understand the influence of these barriers on farmers' decision making, farmers in interviews have consistently pointed out that the transition from animal-intensive systems to horticulture would not be an easy task. Many farmers think that to move to horticulture is too risky because they perceive the commodity price fluctuations as too uncertain. They also perceive high risk from not having a defined buyer, unlike the case for dairy (the dairy market structure is well consolidated across regions, which is not the case of other non-animal sectors). New unfamiliar activities will also tend to involve more risk, particularly when there is not a large community of other farmers carrying out these activities nearby. The skills involved in horticulture (or forestry) are also clearly quite different, so a shift involves abandoning significant human capital and the need to invest in new knowledge and skills. New skills may take years, if not a generation, to fully develop.

However, perhaps the stronger barriers to changing land use are given by behavioural factors. Among the most relevant behavioural barriers likely to affect land-use change in the future are:

- First cost bias: In the context of an investment with significant up-front costs, such as land-use change, decision makers tend to place a disproportionately large weight on the initial cost.

- Habitual behaviour: Farmers may perceive on some level that to transition to new land uses could be helpful for their farms, but they just do not want to be bothered with the new behaviours that this change would imply. As one farmer said: "*I like to be a dairy farmer, and as a dairy farmer I will retire.*"

Externalities are where the full costs and benefits of an action are not borne by the decision maker. In this paper we are explicitly addressing the externality associated with GHG emissions. However, if the policies to encourage land-use change as a mitigation option are inefficiently designed or implemented, or if farmers do not regard the policies as credible in the long term (so don't fully internalise the cost), actual land-use responses will fall short of those modelled. Other externalities may not be fully considered, in particular the "learning" externality. The first farmers in an area to convert to a particular type of horticulture will learn a lot and others will benefit from this learning. They may also induce necessary changes in regulation or market infrastructure at considerable cost. The farmer making a conversion may not consider these benefits to others.

Even though many of the barriers across these seven categories have been studied in different farming contexts in other countries, their study in New Zealand is limited and generally focused on a very specific adoption of practice(s) and/or technologies. There is not much New Zealand evidence about barriers to land-use change.[37] An exception to this is studies looking at Māori landowners, where it has been shown that some barriers do influence land-use decisions among Māori groups.

6.2.1 Land-use change barriers in the Māori context

The current institutional arrangement that governs Māori land has been inherited, and it is a mixture of customs, traditions, and the results of the English Crown legislation introduced in 1862 (Durie, 1998; Kingi, 2004). As a result, Māori land ownership has been passed on through successive descendant generations of the former owners, and individual interests in the same block of Māori land have been registered, creating multiple owners and interest (Kingi, 2008). Māori land can be administered using several governance structures that were designed to help Māori to coordinate decision-making processes among multiple owners and reduce internal transaction costs (White, 1997; Kingi, 2008).

In an investigation into four case studies on Māori land blocks with different types of governance structures, Funk (2009) aimed to identify what factors affect a particular governance structure's adoption of carbon farming and how. The results of this study suggested that the final decision of allocating land and adopting carbon farming as a land use

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[37] A list of studies looking at barriers to decision making in farming contexts in New Zealand is available here: https://motu.nz/our-work/environment-and-resources/agricultural-economics/no-cost-barriers/database-of-evidence-on-barriers-to-adoption-in-agriculture-in-new-zealand-and-overseas

can be affected because owners, managers, and decision makers engage at different points along the decision-making process.[38]

On the other hand, the inability to finance investments can impose restrictions on the adoption of land-use change (Jaffe, 2017). This can be denoted as a capital market failure barrier (part of the "market structure and institutions" category). In fact, some studies have indicated that decisions to adopt new technologies or to make investments with positive environmental and economic benefits (like afforestation of marginal land) need to deal with constrained access to loans (e.g. Kingi, 2008; Ministry of Agriculture and Forestry, 2011; West et al., 2016). Daigneault, Wright, and Samarasinghe (2015) examine how to improve land-use potential and to increase economic returns within a specific rohe or territory. They combined biophysical assessment and economic land-use models to identify where each land-use opportunity would be physically and economically feasible by modelling the profits of different land-use options relative to the current land use. They conclude that financial restrictions could limit the final decision of land-use choice.

Related to the barrier of "risk and uncertainty", some studies refer to Māori concerns about participating in permanent forest protection schemes or other schemes. These concerns about risk relate to retention and control of their land, costs associated with joining Government schemes (such as penalties or liabilities), and terms of a carbon payment mechanism (Harmsworth, 2003; Harmsworth, Tahi, and Insley, 2010). Similar constraints are documented on land-use development, where control and retention can represent a big obstacle to making decisions on land use (Carswell et al., 2002; Kingi, 2009; Reid, 2011).

Barriers associated with behavioural factors are the most documented in different studies on Māori farms and Māori land ownership. Māori landowners cannot be considered only as agents who seek to maximise their profitability. In fact, the decision-making process regarding the Māori land use or management requires a balance among sociocultural, environmental, and economic objectives. Cultural values influence decisions as land is considered a basis of identity (Durie 1998; Dewes, Walzl, and Martin, 2011; Mead, 2016), but at the same time land plays an important role as a basis of capital (Kingi, 2008).

6.3 Social and local community impacts of changes

Land-use changes have impacts on the owners of the land, those who work on the land, those within the sector servicing the farms or making use of the farm production, and the local communities where the farmers and their families live and spend money.

The modelling suggests that the aggregate economic and employment impacts could range from a small negative to a large positive effect. This masks significant variation across

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[38] Funk (2009) documents a case study where the negotiated contract for carbon farming was rejected due to lack of support by one of the members of the trust, although the proposal was strongly supported by the lessees who would manage the land and who felt strongly that carbon farming would play a valuable role on some areas of the farm.

sectors and geographic areas. Some sectors are likely to experience large expansions (e.g. forestry and horticulture) while others may suffer significant declines (e.g. extensive sheep and beef). This will lead to heterogeneous geographical impacts, depending on the suitability of local land for horticulture and forestry.

Timar (2016) shows this heterogeneous effect for sheep and beef farmers in a situation where they face both a reward for forestry sequestration and a cost for biological emissions. Farmers on North Island hill country are most likely to convert to forestry from either pasture or scrub; land retirement is most likely to occur on hill country in either island. In contrast, in our modelling, conversions into horticulture are most likely to occur on land that is currently used for dairy or intensive sheep farming.

Within sectors and geographic areas, some farmers will respond rapidly to pressure for land-use change while others will be more cautious, or change could be delayed until the current farmers retire or sell the land. The changes we project in aggregate are gradual but could be very rapid in specific locations.

One response to land-use change, and the resulting employment effects, is labour migration. A classic paper (Blanchard and Katz 1992) found that in the United States, several effects occur after a negative shock. Nominal wages fall and this leads to a small amount of new job creation but mostly induces out-migration. House prices are a good indicator of the attractiveness of living in a particular place, as well as a critical component of the cost of living. Housing prices fall significantly in affected areas, which is bad for home owners, but for renters or new buyers it means that the cost of living falls to at least partly offset lower wages. Migration out of the affected area seems to be driven mostly by unemployment rather than lower wages. More recent US studies (Kaplan and Schulhofer-Wohl 2017; Molloy, Smith, and Wozniak 2014) point to a slowdown in geographic mobility and a concern that this slowdown will impede spatial labour market adjustment; that could imply persistent regional unemployment (or underemployment) after shocks and sustained low wages. This could be of particular relevance to Māori with strong attachments to specific locations.

In Europe, Decressin and Fatas (1995) found that changes in labour force participation (i.e. some people choosing not to participate in the labour market – this could be young people choosing to study, old people retiring early, or women with children choosing to work less) were the key response to a negative shock rather than out-migration. This would affect household incomes in the local community. In Australia, Debelle and Vickery (1999) found that out-migration was a key response to negative shocks, that most of the migration happened within four years, and that the process of adjustment was complete after seven years.

In New Zealand, Maré, Grimes, and Morten (2009) found that migration is a major adjustment response. They also found that employment shocks have strong effects on national house prices but do not identify a regional effect. Grimes and Hyland (2013) found significant effects of commodity price shocks on house prices in regions whose economies depend heavily on the sectors affected by those shocks, but curiously found the strongest effects on urban rather than rural areas. These broad-scale analyses are likely to mask local variation in response.

Grimes and Young (2011) compared adjustment in one isolated and one less isolated community. They found that "When small towns experience a major infrastructure shock, such as a 'mill' closure, the effects can be devastating." They also found that while both the towns experienced large employment and migration effects from a negative shock, these effects were temporary for the town close to a city but more permanent for the isolated community. They also found evidence that homeownership stifled migration responsiveness in the face of a shock. This suggests that not only will homeowners suffer losses in wealth with negative shocks, but they are also likely to be more exposed to weaker labour markets, i.e. lower wages and higher unemployment.

Social impact studies complement these economic results. Taylor, Fitzgerald, and McClintock (1999) synthesise a series of studies on the experience of New Zealand resource-dependent communities, such as those which will be affected by the land-use changes our modelling suggests, through the 1980s and 1990s. These studies were carried out through a research programme "Resource Community Formation and Change".[39] During this period rural communities experienced dramatic shifts in land-sector profitability. Key drivers were the 1980s reforms when agricultural subsidies were removed, exchange rates were floated and rural land values fell by around 50%, and the forestry planting boom in the early 1990s. These changes were associated with gradual but ultimately large land-use changes. Thus, the experience of these communities is highly relevant to anticipating the effects of a similar scale of projected land-use change as we adjust to a low-emissions economy. The land-use changes that will enable cost-effective mitigation will not, however, necessarily be associated with the same direct losses in income and wealth that were experienced after the loss of subsidies.

Their synthesis found that populations in resource-dependent communities generally fell and that key community people were lost. Job losses in rural communities at that time were compounded by substantial industry restructuring (not directly related to land-use change) and wider socioeconomic changes, such as centralisation of social services. They also found that "Low cost housing has attracted newcomers, often characterised by low social-economic status, higher proportions of Māori, more social and cultural diversity, and reduced community cohesion." Their work also suggests that "industry restructuring, economic diversification and

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[39] The individual studies can be found at http://www.tba.co.nz/projects/frstproject_tbsx0001.html.

increased individual and occupational mobility have weakened occupational and community identity".[40]

Positive shocks (such as an expansion of horticulture) with resulting higher land values and employment demand can also create significant changes within communities. MacCrostie Little and Taylor (2001) found that a move towards irrigated land uses was associated with a demographic shift in farming towards the "young and enthusiastic". In-flows of people with different skills could initially be destabilising for the community, and the leadership role of those families who remain was critical in the interim. As the new community stabilised there were positive effects on schools, sports and recreation, and social services, strengthening the rural community. The impacts were not limited to the farming families but also affected those who provide farm services from local service towns. Some towns were able to take advantage of the new service demands and benefitted while others lost as their traditional base was eroded.

7 Conclusion

This report has focused on how changes in the way land is used can mitigate greenhouse gas (GHG) emissions and help New Zealand to meet its short- and long-term targets as it transitions to a low-emissions society. It focuses on efficient land-use responses that could be implemented by landowners and does not provide any insight about who should bear the costs of those changes. The main project objective was to estimate the likely extent and nature of land-use change as part of a cost-effective response to different land-sector mitigation targets and the potential economic and social impacts of these changes.

What changes are required to reduce net emissions from the land sector beyond current policy by 50% by 2050? Significant but not historically unprecedented increases in forestry and decreases in sheep beef are critical. The levels of implied regulatory pressure (modelled as emissions prices) is high but in the globally expected price range. If horticulture can expand significantly, if the dairy sector contracts, or if there is a technological breakthrough that allows deep reductions in emissions on farms, the changes into forestry and out of sheep and beef farming are significantly reduced. Facilitating and encouraging these changes will likely require strong, credible positive or negative price incentives but will also require effective complementary policies to facilitate positive behaviour change.

What would the implications of these changes be for the economy as a whole, for agricultural production, and for employment? At an aggregate level, the direct impact of the land-use mitigation could impose a small long-term cost, or could lead to significant gains if

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[40] A CRESA research programme on building attachment in families and communities also considered the impacts of migration on individuals, families and communities. https://cresa.co.nz/projects/building-attachment-in-families-and-communities/

horticulture can expand. This does not include the reduced cost to New Zealand of meeting our overall mitigation targets. Employment effects are positive in aggregate, with increases in forestry employment more than offsetting losses in sheep-beef and dairy employment, and large increases if horticulture expands significantly. Production losses from existing pastoral agriculture are relatively small because of the low productivity of the land that is likely to move into forestry and the relatively small areas likely to convert to horticulture.

Can we reduce net emissions from the land sector beyond current policy by 30% by 2030? Yes, it is feasible, but it would be difficult because of the speed of change required. Land-use change is slow for good reasons. Trying to go fast would impose stress on farmers, the farm sector, and their communities and could lead to bad economic decisions.

Beyond 2050, a low-emissions transition path that depends heavily on forestry will need to shift focus to permanent, non-harvested forests to extend the period of positive net sequestration. If we need to make deep long-term emissions cuts, a path that includes significant horticultural expansion will likely be more cost-effective than one that depends heavily on on-farm mitigation technologies.

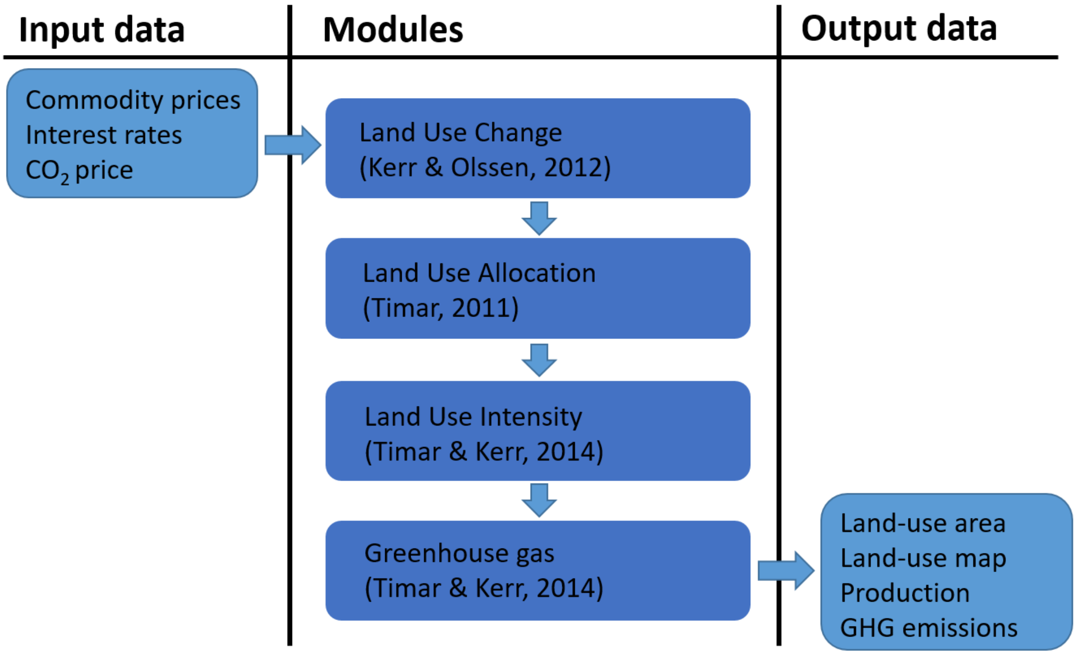
Appendix A: LURNZ model detailed description

The LURNZ model and its applications have been described in more detail elsewhere (e.g. Anastasiadis et al., 2014; Kerr et al., 2012; Timar, 2016). For the purpose of this paper, there are a few key points about the structure of the model. These are summarised in Figure 17. Projected commodity prices for each year over the simulation period (to 2050), projected GHG emissions, CO_2 prices (translated into impacts on implicit commodity prices), and interest rates are fed into the Land Use Change module. This module is based on the historical, dynamic response of land-use shares to commodity prices and interest rates. It assumes that agents predict future prices based on historical prices only, and it accounts for the cost of land-use change. Because of adjustment costs, changes occur gradually over years in response to a change in prices.

The results of the changes in national land-use shares are fed into the Land Use Allocation module, which uses estimates from an econometric model to predict the most likely pixels of land on which any increases or decreases in each land use are likely to be located. The national share of land in horticulture does not respond to commodity prices, but the location of any increase in horticulture is determined by the Land Use Allocation module (Timar, 2016).[41]

Finally, the Land Use Intensity and Greenhouse Gas modules jointly produce estimates of production and the GHG emissions from the four main rural land uses.

Figure 17. Summary of the LURNZ model mechanics



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[41] Technically, the horticultural land use in LURNZ is considered an "exogenous" land use, so its changes over time are imposed by simulation drawn by the research team. As a consequence, only aggregated values about potential horticultural expansion are included in this study (as shown below). The horticultural expansions assumed in the scenarios of this project were consulted and agreed with MPI/BERG.

Table 16. Additional assumptions used in LURNZ mitigation scenarios

	Mitigation scenarios
Emissions Price Pathway	Observed prices until 2017, price required to meet targets from 2018, increasing at real interest rate annually thereafter (approx. 1.8%).
ETS Coverage	All emissions in ETS from 2020 as a proxy for efficient policy on agricultural emissions.
ETS Free Allocation	Implicit price pressure on agricultural emissions: 5% of ETS price with current metrics from 2020, rising 3 percentage points annually until 2030; 5 percentage points annually thereafter.

Land Use in Rural New Zealand (LURNZ) is national-scale, spatial model designed to consider the implications of environmental policies on future land use, production, and greenhouse gas emissions. It is a partial equilibrium model (Kerr et al., 2012) that includes all private rural land in New Zealand and can produce annual maps of land use at a 25 hectare resolution.

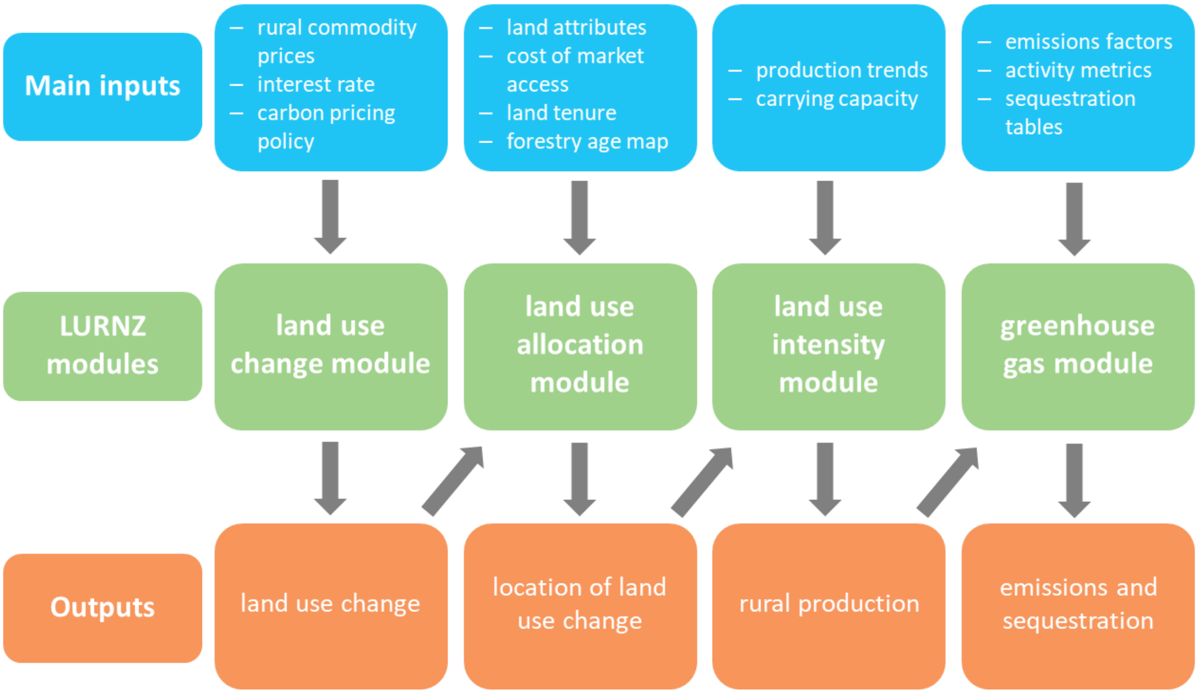
LURNZ can be used to simulate changes in dairy farming, sheep-beef farming, plantation forestry, and unproductive scrub in response to changes in economic incentives. In addition, it can spatially allocate exogenously determined changes for horticulture.

Econometrically estimated models that establish the relationship between observed drivers of land use and land-use outcomes provide the foundation of LURNZ. The revealed preference nature of these models enables us to make relatively few assumptions about farmers' objectives and decision processes: LURNZ results are largely driven by how land use has responded to its main drivers in the past.

Simulations in LURNZ are implemented by running its main modules in a pre-determined sequence (see

Figure 18). The overall amount of land-use change is projected in the **Land Use Change module**, while the spatial location of land-use change is simulated in the **Land Use Allocation module**. LURNZ also includes functions to simulate rural production and emissions (or sequestration) conditional on the simulated land-use outcomes.

Figure 18. A schematic representation of the LURNZ model



The model's underlying datasets and processes have been validated (Anastasiadis et al., 2014), and its results are consistent with data and trends at the national scale, including New Zealand's Greenhouse Gas Inventory (Timar and Kerr, 2014).

Land Use Change module

The Land Use Change module is built around a system of regression equations that estimate dynamic land-use responses to changes in economic drivers, such as commodity prices, at the national level (Kerr and Olssen, 2012, Kerr et al., 2012). The regression includes New Zealand's four major rural land uses: dairy farming, sheep-beef farming, plantation forestry, and unproductive scrub. The coefficients of the model are estimated using historical commodity prices for dairy, sheep-beef, and forestry.[42,43]

Modelling emissions pricing

The effect of an emissions trading environment (including emissions pricing and any free allocation) is modelled through adjustments to commodity prices received in each rural sector. We effectively assume that emissions costs affect farm decision making in exactly the same way as commodity prices do through their effect on profits (Kerr et al., 2012). While this can be

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[42] Milk-solid prices are reported in the Livestock Improvement Corporation's (LIC) Dairy Statistics reports; the sheep-beef price is a composite export unit value calculated from New Zealand's Overseas Merchandise Trade data set; forestry log prices are export unit values that match MPI's values for logs and poles for every year that they report data. For simulations of future periods, we use commodity price projections provided by MPI's Situational Outlook for Primary Industries (SOPI). (SONZAF).

[43] We do not face the same challenges for estimating land-use response to economic returns as US-based studies do because commodity prices in New Zealand are credibly exogenous.

interpreted as the effect of the ETS, it could equally be interpreted as any type of policy that has the equivalent effect on the profit a land user earns – such as a subsidy, a tax, farm education and support, or efficiency gains resulting from R & D.

For dairy and sheep-beef, the effect of emissions prices on commodity prices is determined by calculating CO_2-equivalent greenhouse gas emissions per unit of milk solids and meat produced. We also add a component to account for emissions from fertiliser use in each pastoral sector.

We model the carbon return to plantation forestry as the net present value of carbon credits from the first ten years of forest growth. Land managers' actual valuations of carbon return depend on idiosyncratic parameters that are difficult to model; these include parameters for risk aversion as well as expectations of future emissions prices that may also depend heavily on expectations over future policy.

There is an important way in which using the net present value of carbon credits from the first ten years provides a conservative valuation: the carbon stock at ten years coincides with the minimum carbon stock held on land that is always replanted. Therefore, there is no liability risk from selling the carbon credits accumulated over the ten years after planting. The methods and intuition for calculating the carbon return to forestry are documented in more detail in Kerr et al. (2012).[44]

Policy changes with the expected introduction of averaging rules for forestry could see forest owners earning credits for the first 21 years of forest growth with no emissions price risk. Our methods potentially underestimate the return to forestry under such a policy. However, there are some factors that reduce the magnitude of this error: these include the discounting of returns accruing in the future and the continued existence of risks associated with policy change, as well as the possibility that under the new rules the liability for deforestation might exceed the amount of credits earned.

Finally, under the Emissions Trading Scheme, scrubland can also earn a return for its sequestration. There is no data on historical responses to scrub returns, as scrub has historically never earned a monetary return. Scrub returns are therefore modelled through subtracting the potential carbon reward to scrub from the (already adjusted) commodity price projections of the other sectors (Kerr et al., 2012).

As with all econometric models, the projections of the model are most reliable when drivers of land-use change, the adjusted commodity prices, are within or near their historical ranges. In the output of the Land Use Change module, dynamic projections are linearised over the first ten simulation years to focus on the long-run pattern of land-use change.

Land Use Allocation module

The second, spatial, component of LURNZ is the Land Use Allocation module. In this module, the national level changes in land use are allocated spatially across New Zealand on a 25-hectare resolution gridded map.

The module is parametrised using estimates from a multinomial logit discrete-choice model that relates observed land-use choices to various geophysical characteristics of the land, such as slope and land-use capability class, proxies for cost of market access like distance to towns and ports, and land tenure (Timar, 2011). In addition to dairy, sheep-beef, forestry, and scrub, this estimation also includes horticulture, enabling LURNZ to spatially model exogenous changes in this land use.

The multinomial logit model predicts choice probabilities for each land use at each grid cell. LURNZ uses these probabilities as indicators of suitability. For any given land use, the grid cells with the greatest probability for that use are considered most suitable, while the grid cells with the lowest probability for that use are considered least suitable.

Given total annual changes in each land use and the estimated probabilities, an allocation algorithm assigns changes in land use spatially. The algorithm processes changes in horticultural land, followed by changes in dairy land, in sheep-beef land, and finally in forestry land.

This order gives priority to land uses that are generally more profitable. Changes in scrubland occur as a consequence of changes in the other land uses. The rules within the algorithm are consistent with the intuition that if a land use is expanding, cells most suitable for the use will be converted first. The algorithm also minimises the amount of land-use shuffling across cells; a detailed description of the allocation methodology can be found in Anastasiadis et al. (2014).[45]

The conversion of plantation forestry to other uses is subject to two additional controls. First, LURNZ tracks the age of forests on each cell. Only those pixels that are identified as being of harvestable age (between 26 and 32 years) or as awaiting replanting (age zero) may change land use. Second, if forestry land is increasing, no forestry land may change to another use. On the other hand, if forestry land is decreasing, then the amount of forestry land that changes to another use must not exceed the total decrease in forestry land.

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[45] Compared to Anastasiadis et al. (2014), the rules governing transitions out of sheep-beef use in the allocation algorithm have been modified for this project. Previously, the cells with the lowest estimated probability for sheep-beef were abandoned first; now the sheep-beef cells with the highest estimated probability for scrub are abandoned first. This has improved the feasibility of projections, especially when exogenous constraints on other land uses are included in the simulation runs.

The dynamics and spatial allocation of land-use change in the LURNZ model was left almost unchanged from previous calibration and validation exercises (Anastasiadis et al., 2014).

Land Use Intensity and Greenhouse Gas modules

Using the spatial projections of land use, LURNZ can simulate the associated spatial patterns of rural production and emissions (Timar, 2014). These are completed in the Land Use Intensity and Greenhouse Gas modules, respectively.

In LURNZ, both intensity (production) and emissions are exogenously driven in the sense that they do not respond to changes in economic incentives, such as emissions pricing. In other words, on-farm mitigation is not a response option within LURNZ, though it can be imposed exogenously. To account for expected changes in production and greenhouse gas efficiency over time, LURNZ relies on extrapolating historical trends in the relevant variables. Projected changes in dairy farming involve the use of estimated trends in milk solid production per hectare by region. Estimated sheep-beef intensity varies by farm class and the carrying capacity of the land, but it is not modelled through time. Projected emissions factors for both dairy and sheep-beef farming have been supplied by Reisinger and Clark (2016). The projections run through to 2050, and they reflect increasing GHG efficiency over time in both sectors. To approximate production in plantation forestry, we calculate the area harvested in each year.[46]

Averaging and harvested wood products

Forestry greenhouse gas modelling has been completely revised for this project to reflect the expected introduction of an 'averaging' approach for the sector and changes to national inventory accounting to reflect the timing of emissions from harvested wood products.

Previously LURNZ results were based on UNFCCC accounting rules that lead to large fluctuations over time in net emissions, depending on harvest patterns. Under the revised rules, forests are credited only up to the point of the average carbon stock held in a permanent rotation, as illustrated in

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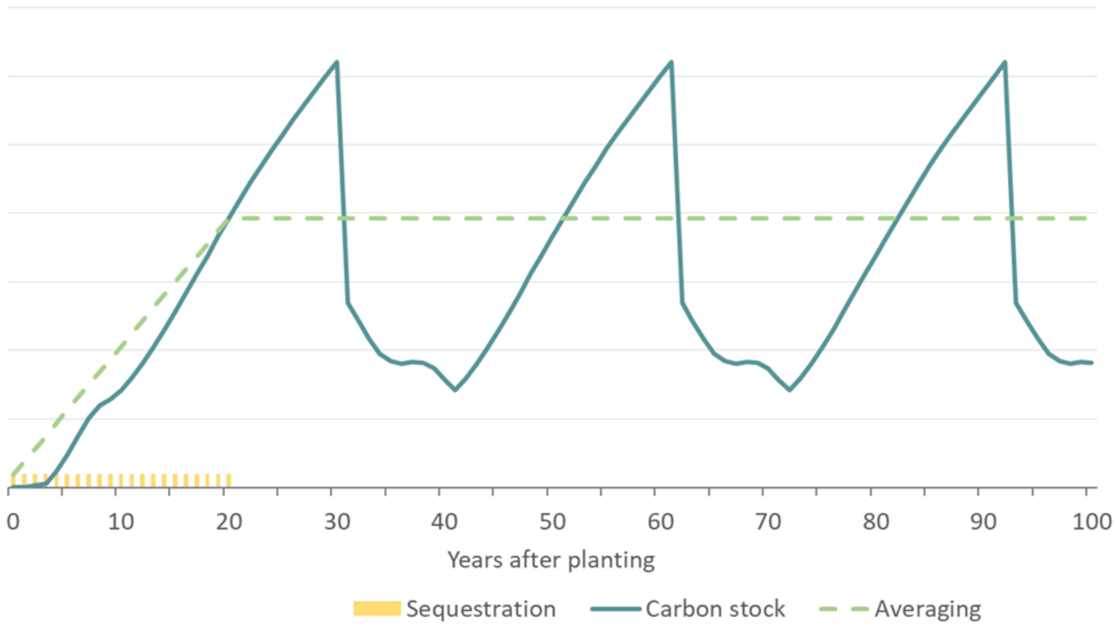
[46] This is not a standard output of the Land Use Intensity module, but it can be reconstructed from data generated in the background by forestry age tracking that runs during spatial allocation.

Figure 19.

Figure 19. The implementation of forestry averaging



The average level of carbon stock is reached 21 years after planting. A linear trend for carbon accumulation up to that point is applied. Based on the *pinus radiata* sequestration profile in the look-up tables underlying the National Inventory, this corresponds to an annual accumulation of 31.83 tonnes CO_2 per hectare over the first 21 years. This is the amount of sequestration we associate with each hectare of new exotic forest land for 21 years after planting.

As the calculation is based on the net growth of forestry area, net forestry emissions are zero by design in the LURNZ base year (2012). However, forests planted in the 21 years before 2012 could also be contributing to removals but are not represented in the results thus far. We make an adjustment for this legacy sequestration by applying the revised accounting rules to net changes in plantation forestry between 1991 and 2012. Therefore, we get an estimate of the contribution of past planting to current and future removals at the beginning of the simulation period. Legacy sequestration falls to zero over time, and from the perspective of achieving a 2050 target, it is immaterial whether or not it is included. However, cumulative net emissions over the period leading up to 2050 are affected by its inclusion.

A few other points on the methodology of forestry modelling deserve some discussion. In LURNZ, we do not consider permanent carbon forests optimised for sequestration rather than harvest. Such forests accumulate carbon at a higher rate and over longer periods. At high emissions prices, some forestry is likely to stop harvesting and move to permanent carbon forestry. Our modelling does not capture this dynamic and could therefore underestimate sequestration (though the effects of carbon forestry would be more pronounced in the second half of the century, which is beyond our simulation horizon). In this sense, LURNZ projections for the sector are conservative.[47]

On the other hand, the controls applied to forestry land-use changes in the allocation algorithm (described in the previous section) mean that LURNZ projects zero deforestation if overall forestry area increases. Emissions associated with deforestation are currently estimated at around 4 megatonnes CO_2 per year. As LURNZ cannot model this component, we expect to underestimate emissions from the sector by 4 megatonnes under current conditions. This bias is expected to become smaller (or disappear entirely) at higher emissions prices, so it is not expected to have a major effect on scenario results.

Scrub

Net emissions from scrubland are relatively small and difficult to model accurately. To approximate it, we assume all scrubland is suitable for regenerating native forests. We apply the average rate of native sequestration over the first 50 years using the default tables for the ETS from the Ministry for Primary Industries (MPI). This gives 6.5 t CO_2/ha per year to net changes in total scrub area relative to the base year. By treating removals and emissions from scrub symmetrically, this approach implicitly evaluates net emissions from scrub relative to the base year.

Specific assumptions for this modelling exercise

This section explains the implementation of different exogenous constraints used for this project.

Horticultural expansion

The Land Use Change module excludes horticulture due to the difficulty of estimating price responses for the sector. This is due in part to the lack of a historical data series and in part to the complexity of the sector: the horticulture category in LURNZ includes orchards, viticulture, and cropping.

However, given exogenous scenarios on overall horticultural area change, the sector can be included at the spatial allocation stage in LURNZ. The low-horticulture scenarios involves a 40% increase in horticultural area to 2050 (approximately 190,000 ha), and the high-horticulture scenario involves a 200% increase over the same period (approximately 940,000 ha). These rates of expansion are significantly higher than observed in historical trends, but they are considered feasible by experts in horticulture.

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[47] Recall from the discussion of the emissions price effect for forestry that the land-use response for forestry in LURNZ is also likely a conservative estimate.

Horticulture changes are dealt with on top of the allocation algorithm, so the most suitable land in any other use can be subject to transition into horticulture. An expansion of horticulture can therefore have flow-on effects to the area of all other land uses.[48]

Constraint on dairy expansion

In all of the scenarios we constrain the expansion of dairy farming: no new land may be converted to dairying beyond 2025. This constraint reflects an anticipation of councils setting water quality limits in their regions.[49]

To implement the constraint, the land-use changes established in the Land Use Change module are overwritten before spatial allocation. To offset the change in dairy area, LURNZ finds the cells that would have transitioned to dairy farming in the absence of the constraint and keeps them in their previous land use. Therefore, the effect on overall land-use shares depends on the mix of land uses that would have changed into dairy without the constraint, which in turn depends on the magnitude and type of pre-constraint land-use change and the distribution of observed land attributes within each land use.

If the constraint on dairy expansion is combined with an exogenous growth in horticultural area, the dairy area may actually decrease in the constrained period as horticulture is allowed to expand into existing dairy land, but new dairy cannot be established.

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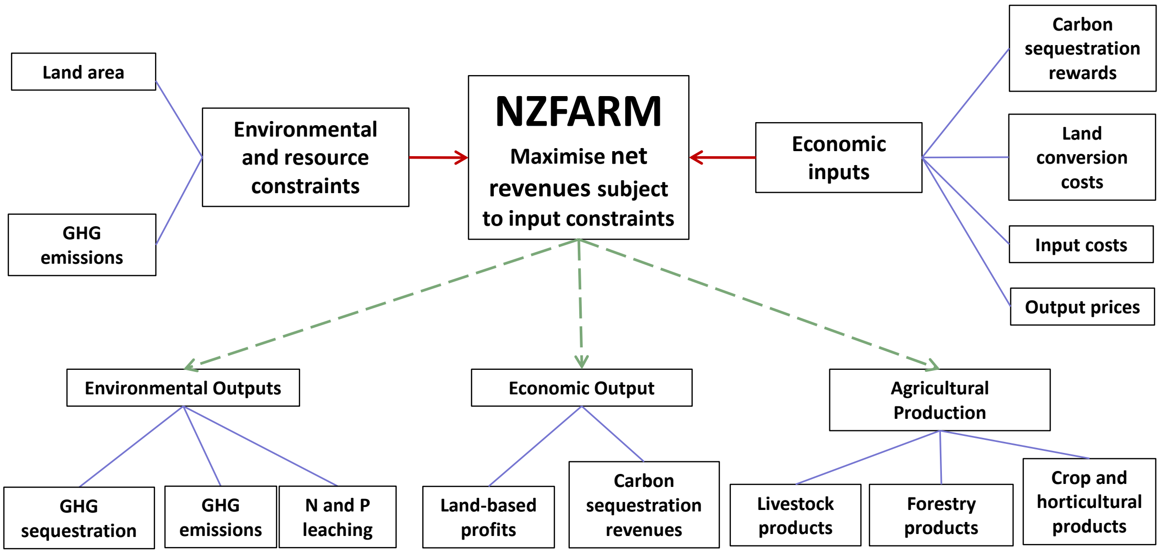
[48] In some previous versions of LURNZ, an offsetting change was only applied to sheep-beef area. Total dairy area was therefore unaffected by horticultural change, though the spatial location of dairy could have been affected. Given the magnitude of horticultural expansion considered in this project, it is no longer considered appropriate to apply the area offset to sheep-beef only.

[49] Without this constraint, dairy area in LURNZ simulations keeps growing even with emissions pricing. Econometrically, this happens because the estimated cross-price effect between sheep-beef price and dairy area outweighs the estimated own-price effect of dairy. Intuitively, emissions pricing has a larger effect on the viability of sheep-beef farming than it does on the viability of dairy farming.

Appendix B: NZFARM model details

A schematic representation of the NZFARM model used for this study is given in Figure 20.

Figure 20. Schematic view of the NZFARM model. Adapted from Daigneault et al. (2012).



The NZFARM model's objective function is to determine the level of agricultural production that maximises the summed profits from all regions of New Zealand, subject to:

- land-use options;
- agricultural production costs and output prices; and
- environmental factors (such as land-use area) and environmental constraints (e.g. GHG emissions limits).

NZFARM uses the projected 2030 and 2050 land-use maps from the reference case scenario (land use) produced by LURNZ. To calibrate the land-use area results, we use constant elasticity of transformation (CET) functions and their nested forms.

The NZFARM model identifies optimal land-use practices, i.e. land use is a choice variable. Each land use has different effects on agricultural profits, production, GHG emissions and sequestration, N leaching, and P loss. We include into the model the main farm enterprises and land uses in New Zealand: pasture (dairy, sheep and beef, deer, other pasture), forestry, arable, horticulture (vegetables, fruit, pipfruit, viticulture), native forests and other vegetation under conservation protection area. The products of these land uses include milk solids, lamb, beef and deer meat; sheep wool; wheat, barley, and maize grains; berries, grapes, pipfruit, and kiwi fruit; aggregated vegetables; and timber. In addition, agricultural and forestry land uses emit GHGs, sequester carbon, and leach N and P.

We assume five dairy systems, and several sheep and beef farm production types, such as mixed finishing, finishing breeding, and intensive finishing, and on high and hill country that exist in New Zealand. Forestry (i.e. farm tree plantations) can result in carbon sequestration for farmers. To calculate the annual profits of forestry we considered the annuity of this land use. Furthermore, we assume that farm enterprises can change their land uses and that farm managers do not consider the change in management practices, such as changes in fertiliser and stocking rates.

The model's objective function is to determine the level of agricultural production that maximises the summed profits from all regions of New Zealand, subject to land-use options, agricultural production costs and output prices, environmental factors such as land-use area, and environmental constraints (e.g., GHG emissions limits) imposed on the country. The objective function of the model maximises the profits from land uses for all of New Zealand. We assume in the model the earnings before tax and interest from land uses. In more detail, the mathematical representation of the objective function is:

$$Max\ NR = \sum_{r,l,e} \{PQ_{r,l,e} - X_{r,l,e}[\omega^{live}_{r,l,e} + \omega^{vc}_{r,l,e} + \omega^{fc}_{r,l,e}] + \tau\ env_{r,l,e,o} X_{r,l,e}\} \tag{1}$$

where NR is the maximum level of profits for New Zealand, P is the product output price, Q is the product output, Y is other gross income earned by farmers, X is the farm-based activity, ω^{live}, ω^{vc}, ω^{fc} are the respective livestock, variable, and fixed input costs, τ is a payment for carbon sequestration in forestry activities, o includes a C sequestration level coefficient in forestry. Summing the revenue and costs of production across all NZFARM regional zones (r), land uses (l) such as pasture, forestry, arable, horticulture, native land and other land, and farm enterprises (e) such as dairy, sheep and beef, deer, other pasture, vegetables, fruit, pipfruit, viticulture, arable, farm forestry, conservation area and other land yields the total profit for New Zealand. The productivity of land uses and their output and input prices remain constant throughout the analysed periods due to insufficient information to make projections for profits and commodity output levels of all simulated land uses. We assume that only the payment level for C sequestration in forestry changes over the years according to the interest rate.

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

$$Q_{r,l,e} \leq \alpha^{proc}_{r,l,e}\ X_{r,l,e} \tag{2}$$

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

The choice variable in the model is an allocation area of land uses. Land uses in 16 administrative regions that are given in the NZFARM are constrained by the available land area as in:

$$\sum_e X_{r,l,e} \leq L_{r,l} \tag{3}$$

where L is the available land use area, such as pasture, forestry, arable, horticulture, conservation area and other land in each region of New Zealand.

Land use is constrained by the initial land-use allocation and the area of land that the model can change and modify, and this relationship in equation is represented as:

$$L_{r,l} \leq L_{r,l}^{init} + Z_{r,l} \tag{4}$$

where $L_{r,l}^{init}$ is the initially available land-use area that is based on observed situations and $Z_{r,l}$ is the area of land use that can be changed by the model.

The level of land-use change in each region is constrained by the model to be the difference in the area of the initial land-use activity and the area of selected by model the land-use activity:

$$Z_{r,l} \leq \sum_e (X_{r,l,e}^{init} - X_{r,l,e}) \tag{5}$$

where $X_{r,l,e}^{init}$ is the area of the initial land-use activity for each farm type in the regions.

In the model, all managed land uses can be changed to another land use, except urban, native forests, and tussock and grassland under conservation protection area which remain fixed:

$$L_{r,native} = L_{r,native(other)}^{init} \tag{6}$$

where $L_{r,native(other)}^{init}$ is the area of urban and conservation land initially given in the model.

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

$$X_{r,l,e} = X_{r,l,e}^{init} \tag{7}$$

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

The NZFARM model also calculates the change in environmental outputs when the land users maximise profits. We consider GHG emissions, C sequestration, N leaching, and P loss as environmental outputs resulting from land uses. The equation for environmental outputs is included into the model as follows:

$$env_{r,l,e,o} X_{r,l,e} = EN_{r,l,e,o} \tag{8}$$

where env is the coefficient of environmental indicators such as GHG emissions, C sequestration, N leaching, and P loss from land uses, EN is the variable of environmental outputs from selected land uses by the model, and o is the set that consist of environmental indicators.

The important equation in the model that affects the land-use change is the constraint on GHG emissions from land uses. It is assumed that the sum of emissions from all land should not be higher than the certain national GHG emissions level from agriculture (see section 1.3 on scenario description):

$$\sum_{r,l,e} env_{r,l,e,GHG} X_{r,l,e} \leq \sum_{r,l,e} \delta emis_{r,l,e,GHG}^{init} \tag{9}$$

where δ is the target level (in percentage) of GHG emissions and $emis_{r,l,e,GHG}^{init}$ is the initial (reference casein each period) GHG emissions levels from land uses.

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

$$Q, X, L \geq 0 \tag{10}$$

The model is solved using the General Algebraic Modelling System (GAMS).[50]

Parametrisation and calibration

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

The model is parametrised where responses to GHG emissions constraints and C sequestration rewards are not drastic and assumed to be instantaneous. The optimal distribution of farm type, land use, and agricultural output in regions of New Zealand are determined using a nested framework that is calibrated based on shares of initially included areas of land uses in each modelled region. At the highest levels of the nest, land use is distributed over the NZFARM regional zones based on the fixed area of various farm enterprises types that generate the maximum profits. A set of land management practices are then imposed on an enterprise, which then determines the level of agricultural outputs produced in the final nest.

NZFARM simulates allocation of farm activity areas through constant elasticity of transformation (CET) functions. The CET function specifies the rate at which regional land inputs, enterprises, and outputs produced can be transformed across the array of available options. This approach is well suited to models that impose resource and policy constraints as it allows the representation of a “smooth” transition across production activities while avoiding unrealistic discontinuities and corner solutions in the simulation solutions (de Frahan et al., 2007). At the highest levels of the CET nest, land use is distributed over the zone based

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

on the fixed area of regions. Land cover is then allocated between several enterprises, such as arable crops, livestock (e.g., dairy or sheep and beef or deer), or forestry plantation, that will generate the highest profits for the country.

The CET functions are calibrated using the share of total initial (observed) area for each element of the nest and a CET elasticity parameter for the respective regions, land area, farm enterprise, and agricultural output. These CET elasticity parameters can range from 0 to infinity, where 0 indicates that the input (e.g. land-use area) is fixed, while infinity indicates that these inputs are perfect substitutes. We do not consider costs from switching from one land use or enterprise activity to another, such as change in infrastructure, learning management practices for new farming, and other costs.

The CET parameters in NZFARM ascend with each level of the nest between land cover, enterprise, and land management (in this study, however, we consider that there is no land management option). This is because farmers have more flexibility to change their mix of management and enterprise activities than to alter their share of land cover. The elasticities are related land cover, enterprise, and land management. The CET elasticity values were assumed to increase over years to consider that farmers are more likely over the long-run to select any of the simulated land uses to meet the environmental constraints and maximise profits. The elasticity values are –2 and –12 for farm enterprise and land-cover change respectively in 2030. We assume 20% increase in elasticity values in 2050 due to possible increase over time in farmers learning the management of different land uses, and accordingly we have elasticity values of –2.44 for farm enterprise and –14.44 for land-cover change. The higher the magnitude, the more the enterprise and land-cover change can be simulated. Note that in comparison to previous studies that used NZFARM (Daigneault et al., 2012, 2018), in this version of the model we do not consider the land management practices. However, this approach constrains changes in adoption of land management practices, such as different stocking and fertiliser rates that may lead to maintaining or increasing profits while reducing GHG emissions.

To populate the data requirements of NZFARM, information from five dairy farm systems on profits, milk-solid production, stocking rate, and environmental outputs was obtained from DairyNZ. DairyNZ also conducted modelling using OVERSEER[51] to estimate GHG emissions levels[52] and N leaching and P losses from dairy farms. Data were obtained on different sheep and beef farm systems from Beef+Lamb New Zealand's sheep and beef farm survey. The survey provided information on profits; stocking rate of sheep, beef cattle, deer and goats; wool production; and meat production from lamb, beef, and deer. To calculate the GHG emissions from all land uses except dairy (as noted above), we used New Zealand's GHG inventory

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[52] In this study we consider only the biological emissions from farming and thus we subtracted embodied GHG emissions from the OVERSEER GHG emissions results for dairy farms.

approaches and considered only biological emissions (MfE, 2017a). In calculating GHG emissions from sheep and beef, we considered the stocking rate and fertiliser application levels, and in calculating emissions levels from other land uses, we considered fertiliser application levels and estimated emissions using equations as given in New Zealand's GHG inventory (MfE, 2017a). We also obtained information from Horticulture New Zealand[53] on EBIT, crop yields, fertiliser application levels, and area distribution of fruit, pipfruit, vegetables, and viticulture. EBIT and GHG emissions of arable crops were obtained from Daigneault et al. (2018).

Forestry production data is obtained from the CenW model, which is a forest growth model that uses climate and nutrient estimates to simulate timber yields (Kirschbaum, 1999). The forest C sequestration rates include carbon in all components of a forest, namely the stem, branches, leaves, roots, and in the coarse woody debris and fine litter on the forest floor. The stand-level dynamics of CenW are explicitly linked to C and nutrient cycling. NZFARM uses the timber and C sequestration outputs of *Pinus radiata* plantations from the CenW model. In NZFARM, the forest rotation is 30 years and we assume that trees are harvested and immediately replanted. The C sequestration rate per hectare in forestry is assumed to be the same in 2012, 2030, and 2050.

The NZFARM model results show that the simulated baseline land use pattern does not differ substantially from the observed data in 2012 or from the LURNZ reference case data (The NZFARM 2030 and 2050 reference cases were calibrated using the LURNZ land use projections, see Table 19). This means that our model is well calibrated and is close to the observed situation. The main difference between the baseline land uses of 2012, 2030, and 2050 is due to a difference in sheep and beef area in 2012: the LURNZ model excludes 0.43 million hectares of pasture located in public land from the total sheep and beef land. (LURNZ therefore assumes that this land cannot be changed as private landowners do not have the right to change its use.) This difference of 0.43 million hectares in the set-up of initial land covers is less than 3% of the total land under main analysis across models (forestry, pastures, horticulture, and scrub) and should not mean important differences from the results provided here.

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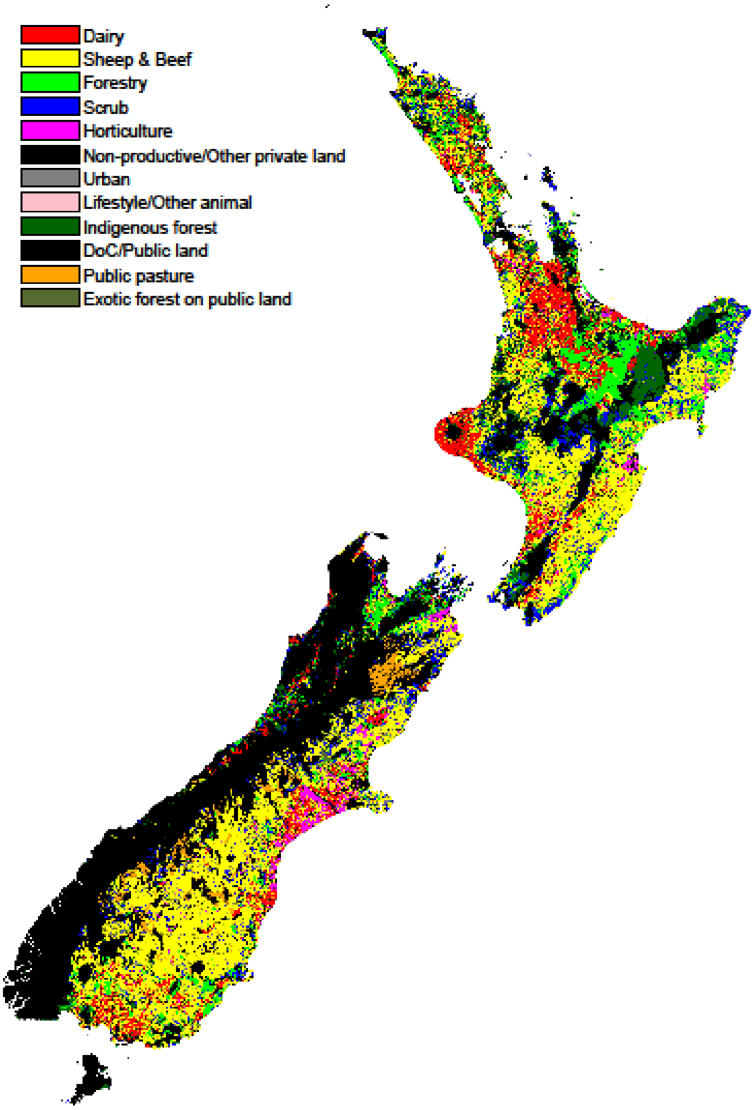
[53] http://www.hortnz.co.nz/

Appendix C: Land-use categories and base data

LURNZ and NZFARM use a consistent base-year land-use map that was developed for a project modelling the implications of freshwater reforms for land-based GHG reductions (Daigneault et al., 2016). This national land-use map (created from AgriBase and LCDBv4) covers the whole range of agricultural and forestry land uses for New Zealand in 2012. The final base map of land use in 2012 used in this project was provided by Landcare Research and is shown in Figure 21.

Figure 21. Land use in 2012 in the base map



This base-year land-use map for 2012 is the latest available, and the distribution of land uses shown in Figure 21 are detailed in Table 17.

Table 17. Land uses in New Zealand in 2012 – values used as baseline for LURNZ.

Land-use Category	**Total Area in 2012**	
	Area (mill ha.)	**Share (%)**
Dairy	2.10	7.8
Sheep and beef	8.15	30.3
Forestry	2.00	7.4
Scrub	1.74	6.5
Horticulture	0.47	1.8
Non-productive and other private	2.16	8.0
Indigenous forest	1.69	6.3
DoC and public land	8.09	30.1
Pasture on public land	0.43	1.6
Exotic forest on public land	0.04	0.1
Total	26.88	100.00

This land-use distribution is aggregated and considered differently across LURNZ and NZFARM, as their respective algorithms analyse land-use change given specific aggregations. The land-use categories within each model are described in Table 18.

Table 18. Land-use aggregation in NZFARM and LURNZ

Land-use Category	**NZFARM Land Use**	**LURNZ Land Use**
Dairy[54]	Dairy	Dairy
Drystock	Sheep and beef, deer	Sheep and beef
Arable	Arable crops (wheat, barley, maize)	Included in horticultural area
Horticulture	Horticultural systems include: Grapes, Fruit (kiwifruit, berries) Pipfruit and Aggregated vegetables	Constant horticultural area
Forestry	Forestry	Forestry
Native bush & scrub	Native bush & scrub	Native bush & scrub[55]

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[54] LURNZ considers both effective and non-effective dairy land, whereas NZFARM restricts its analysis to include only effective land under dairy. Dairy area is 2.1 million hectares in the base map (as shown in Table 18), which is the total area of dairy farms considering both effective and non-effective hectares. According to DairyNZ and the Livestock Improvement Corporation (LIC), effective hectares in dairy in 2012 totalled 1.6 million hectares. Thus, it is assumed that the ratio of effective hectares to hectares in dairy (0.78) holds across years to come. This ratio is used to calculate milk solids and emissions per hectare. As mentioned, NZFARM uses the figure for effective hectares in dairy rather than total hectares.

[55] Not including indigenous forest which is assumed to be unaltered in all scenarios.

Appendix D: ESSAM CGE model closure assumptions

The following model closure rules are adopted for the alternative scenarios, consistent with generally accepted modelling practice:[56]

1. The current account balance is fixed as a percentage of GDP. This means, for example, that if New Zealand needs to purchase international emissions units to meet an emissions responsibility target, that liability cannot be met simply by borrowing more from offshore with unknown or indefinitely deferred repayment.
2. The post-tax rate of return on investment is unchanged between scenarios. This acknowledges that New Zealand is part of the international capital market and ensures consistency with the preceding closure rule.
3. Any change in the demand for labour is reflected in changes in wage rates, not changes in employment. Instead of fixed employment, wage rates could be fixed at reference case levels. This would imply, however, that the long-run level of total employment is driven more by emissions policy in agriculture than by the forces of labour supply and demand, which we consider unlikely.
4. The fiscal balance is fixed across scenarios. This means, for example, that if the government needs to purchase overseas emissions units, it must ensure that it has matching income. If it earns insufficient income from the sale of domestic emissions units (because of free allocation for example), it would have to adjust tax rates. We assume that net personal income tax rates are the default equilibrating mechanism, although changing government expenditure is an alternative option that could be used.

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[56] NZIER and Infometrics (2009). “Economic Modelling of New Zealand Climate Change Policy.” Report to Ministry for the Environment, May 2009. And “Macroeconomic Impacts of Climate Change Policy: Impact of Assigned Amount Units and International Trading.” Report to Ministry for the Environment, July 2009.

Appendix E: Detailed results

Table 19. LURNZ land-use projections under each scenario, 2050 target

Land-use Category	Scenario	2012	2030	2050
Dairy	Reference	2.10	2.30	2.30
	LA		2.31	2.31
	LALH		2.26	2.18
	HA		2.32	2.32
	HALH		2.27	2.19
	HAHH		2.02	1.68
	HAMit		2.31	2.31
Sheep and beef	Reference	8.15	7.43	7.05
	LA		7.38	6.81
	LALH		7.35	6.78
	HA		7.32	6.54
	HALH		7.29	6.51
	HAHH		7.20	6.40
	HAMit		7.35	6.71
Forestry	Reference	2.00	2.57	3.11
	LA		2.70	3.59
	LALH		2.68	3.53
	HA		2.86	4.08
	HALH		2.84	4.02
	HAHH		2.77	3.78
	HAMit		2.77	3.75
Scrub	Reference	1.74	1.70	1.54
	LA		1.60	1.29
	LALH		1.62	1.32
	HA		1.50	1.06
	HALH		1.51	1.09
	HAHH		1.56	1.20
	HAMit		1.56	1.22
Horticulture	Reference	0.47	0.47	0.47
	LA		0.47	0.47
	LALH		0.56	0.66
	HA		0.47	0.47
	HALH		0.56	0.66
	HAHH		0.92	1.42
	HAMit		0.47	0.47

Notes: LA means “low ambition”; HA means “high ambition”; LH means “low-horticulture expansion” and HH means “high-horticulture expansion”; so LALH means “low ambition, low horticulture” and HAHH “high ambition, high horticulture”. HAMit means “high ambition, mitigation technology breakthrough”.

Table 20: Implied LURNZ estimates of employment by land use as percentage differences relative to the reference case

Land-use Category	Reference Case Employment (FTE)	HA Scenario (% change from reference case)	HAHH Scenario (% change from reference case)
Simulation results for 2030			
Dairy	51,992	1	-13
Sheep and beef	41,329	-1	-4
Forestry	7,988	11	11
Horticulture	22,000	0	95
Simulation results for 2050			
Dairy	57,031	1	-28
Sheep and beef	40,606	-4	-9
Forestry	9,671	31	29
Horticulture	22,000	0	200

Table 21: NZFARM estimates of areas in percentage differences in relation to the reference case

Land-use Category	Reference Case (in thousand ha)	LA Scenario (% change from reference case)	HA Scenario (% change from reference case)
Simulation results for 2030			
Dairy	2,299	-4	-8
Sheep and beef	7,820	-4	-8
Deer	214	-3	-6
Other pasture	228	-5	-10
Arable	341	2	3
Forestry	2,598	15	30
Fruit	38	2	4
Pipfruit	16	-1	-3
Vegetables	37	1	2
Viticulture	42	0	-1
Simulation results for 2050			
Dairy	2,299	-7	-14
Sheep and beef	7,029	-7	-15
Deer	214	-6	-12
Other pasture	228	-8	-16
Arable	341	3	5
Forestry	3,320	20	40
Fruit	38	4	8
Pipfruit	16	-2	-4
Vegetables	37	2	4
Viticulture	42	0	-1

Notes: LAEH = low-ambition, endogenous horticulture scenario; HAEH= high-ambition, endogenous horticulture scenario.

Table 22: NZFARM estimates of profit in the reference, low-, and high- ambition scenarios in 2030 and 2050

Land-use Category	**Reference Case (in millions of $NZD)**	**LAEH Scenario (% change from reference case)**	**HAEH Scenario (% change from reference case)**
Simulation results for 2012			
Dairy	2,676		
Sheep and beef	2,807		
Deer	125		
Other pasture	27		
Arable	563		
Forestry	1,183		
Fruit	278		
Pipfruit	101		
Vegetables	442		
Viticulture	666		
National profit	*8,869*		
Simulation results for 2030			
Dairy	2,940	-4	-8
Sheep and beef	2,577	-4	-8
Deer	125	-3	-6
Other pasture	27	-4	-7
Arable	563	2	3
Forestry	1,505	13	27
Fruit	278	3	4
Pipfruit	101	-1	-2
Vegetables	442	1	2
Viticulture	666	0	0
National profit	*9,225*	*-0.02*	*-0.09*
Simulation results for 2050			
Dairy	2,940	-7	-13
Sheep and beef	2,313	-7	-15
Deer	125	-6	-12
Other pasture	27	-7	-14
Arable	563	3	5
Forestry	1,906	17	35
Fruit	278	4	8
Pipfruit	101	-1	-3
Vegetables	442	2	4
Viticulture	666	0	0
National profit	*9,362*	*-0.04*	*-0.2*

Note: due to the fact that the native and other land-use areas are assumed to be fixed, we do not depict the profits from these land uses.

Table 23: NZFARM estimates of land-use GHG emissions in the reference, low(LAEH)-, and high(HAEH)-ambition scenarios in 2012, 2030, and 2050

Land-use Category	**Reference Case (in kt. CO_2-e emissions)**	**LA Scenario (% change from reference case)**	**HA Scenario (% change from reference case)**
Simulation results for 2012			
Dairy	14,819		
Sheep and beef	24,977		
Deer	778		
Other pasture	783		
Arable	341		
Fruit	10		
Pipfruit	1		
Vegetables	14		
Viticulture	3		
National GHG emissions	*41,727*		
Simulation results for 2030			
Dairy	16,279	-4	-8
Sheep and beef	23,072	-4	-8
Deer	778	-3	-7
Other pasture	783	-5	-10
Arable	341	2	3
Fruit	10	2	4
Pipfruit	1	0	-1
Vegetables	14	1	2
Viticulture	3	-1	-2
National GHG emissions	*42,280*	*-4*	*-8*
Simulation results for 2050			
Dairy	16,279	-7	-14
Sheep and beef	20,635	-8	-15
Deer	778	-6	-12
Other pasture	783	-8	-16
Arable	341	3	5
Fruit	10	4	8
Pipfruit	1	-1	-2
Vegetables	14	2	4
Viticulture	3	-1	-3
National GHG emissions	*38,844*	*-7*	*-14*

Note: Low- and high-ambition scenarios are simulated for 2030 and 2050.

Table 24: NZFARM estimates of GHG emissions (and C sequestration in forestry) in the reference, low-, and high-ambition scenarios in 2012, 2030, and 2050

Farm Enterprise	**Reference Case (kt. CO_2)**	**Low-ambition – Endogenous Horticulture (kt. CO_2)**	**High-ambition – Endogenous Horticulture (kt. CO_2)**
Simulation results for 2012			
GHG emissions from agriculture	41,727	n.a.	n.a.
C sequestration in forestry	-28,785	n.a.	n.a.
Net GHG emissions from agriculture and forestry	12,942	n.a.	n.a.
Simulation results for 2030			
GHG emissions from agriculture	41,280	39,601	37,937
C sequestration in forestry	-29,617	-33,804	-38,008
Net GHG emissions from agriculture and forestry	11,664	5,797	-71
Simulation results for 2050			
GHG emissions from agriculture	38,844	36,072	33,320
C sequestration in forestry	-37,638	-44,645	-51,671
Net GHG emissions from agriculture and forestry	1,206	-8,573	-18,351

Notes: Low- and high-ambition scenarios are simulated for 2030 and 2050; negative emissions levels indicate that GHG sequestration from forestry is larger than GHG emissions from agriculture.

Table 25. Gross output of agriculture and forestry in the reference, low(LAEH)-, and high(HAEH)-ambition scenarios in 2012, 2030, and 2050

Land use category	**Reference case (in $ million)**	**LA (in $ million)**	**HA (in $ million)**
In 2012			
Dairy	9,007		
Sheep and beef	6,484		
Arable	1,009		
Horticulture	2,723		
Forestry	2,516		
In 2030			
Dairy	10,219	10,323	9,942
Sheep and beef	5,874	5,670	5,420
Arable	1,009	861	870
Horticulture	2,723	2,716	2,711
Forestry	3,356	3,759	4,217
In 2050			
Dairy	10,219	9,177	8,484
Sheep and beef	5,488	5,021	4,624
Arable	1,009	1,038	1,062
Horticulture	2,723	2,748	2,764
Forestry	4,065	4,822	5,580

Note: Low- and high-ambition scenarios are simulated for 2030 and 2050.

Table 26 Value added in the land sector: estimates from ESSAM

	HA	**HALH**	**HAHH**	**HA-vac**
		% Δ on Reference		
Horticulture	6.7%	59.0%	214.6%	-0.8%
Sheep & beef farming	-3.3%	-6.7%	-12.8%	0.5%
Dairy farming	0.9%	-5.0%	-27.9%	0.3%
Other farming	2.5%	12.5%	43.2%	0.2%
Forestry	22.3%	21.6%	16.3%	15.7%
Total	5.6%	12.6%	30.8%	2.8%
Initial shock effect on VA	4.4%	9.0%	27.4%	3.1%
Agr+For total change in VA /change in GDP	30.6%	50.5%	72.2%	37.5%

References

Anastasiadis, Simon, and Suzi Kerr. 2013. "Land Use and Farming Intensity: For 1996, 2008 and 2020," *Report for the Parliamentary Commissioner for the Environment*. Motu Economic and Public Policy Research Trust, Wellington, NZ.

Anastasiadis, Simon, Suzi Kerr, Wei Zhang, Corey Allan, and William Power. 2014. "Land Use in Rural New Zealand: Spatial Land Use, Land-Use Change, and Model Validation." *Motu Working Paper 14-07*. Motu Economic and Public Policy Research Trust, Wellington, NZ.

Blanchard, Olivier Jean, and Lawrence F. Katz. 1992. "Regional Evolutions." *Brookings Papers on Economic Activity*, no. 1, pp. 1–75.

Carswell, Fiona, Garth Harmsworth, Suzi Kerr, Rau Kirikiri, and Ian Turney. 2002. "A Framework for Engagement of Maori Landowners in 'Carbon Farming' Using Indigenous Forest Regeneration." Landcare Research Contract Report: LC0102/116, Manaaki Whenua Landcare Research, New Zealand. Available online at www.motu.org.nz

Carver, Tom, Patrick Dawson, and Suzi Kerr. 2017. "Including Forestry in an Emissions Trading Scheme: Lessons from New Zealand." *Motu Working Paper 17-11*. Motu Economic and Public Policy Research Trust, Wellington, NZ.

Carver, Thomas, and Suzi Kerr. 2017. "Facilitating Carbon Offsets from Native Forests." *Motu Working Paper 17-01*. Motu Economic and Public Policy Research Trust, Wellington, NZ.

Daigneault A., S. Elliot, S. Greenhalgh, S. Kerr, E. Lou, L. Murphy, L. Timar, and S. Wadhwa. 2016. "Modelling the Potential Impact of New Zealand's Freshwater Reforms on Land-based Greenhouse Gas Emissions." *MPI Technical Paper No: 2017/22.* Ministry for Primary Industries, Wellington, NZ.

Daigneault, A. J., S. Greenhalgh, and O. Samarasinghe. 2018. "Economic Impacts of Multiple Agro-environmental Policies on New Zealand Land Use." *Environmental and Resource Economics*, 69:4, pp. 763–785. Available online at https://doi.org/10.1007/s10640-016-0103-6

Daigneault A., S. Greenhalgh, O. Samarasinghe, K. Jhunjhnuwala, J. Walcroft, and O. Montes de Oca Munguia. 2012. "Sustainable Land Management and Climate Change – Catchment Analysis of Climate Change." *SLMACC Final Report*. Ministry for Primary Industries, Wellington, NZ. August 2012.

Daigneault A., W. Wright, and O. Samarasinghe. 2015. "Economic Analysis of Land Use Opportunities in Maniapoto Rohe." *Landcare Research Report LC2415*.

de Frahan, B.H., Buysse, J., Polomé, P., Fernagut, B., Harmignie, O., Lauwers, L., Van Huylenbroeck, G., and Van Meensel, J. 2007. "Positive Mathematical Programming for Agricultural and Environmental Policy Analysis: Review and Practice, in *Handbook of Operations Research in Natural Resources, Vol. 99*, A. Weintraub, T. Bjorndal, R. Epstein, and C. Romero, Eds. Springer, Berlin, pp. 129–154.

Debelle, Guy, and James Vickery. 1999. "Labour Market Adjustment: Evidence on Interstate Labour Mobility." *Australian Economic Review,* 32:3, pp. 249–63.

Decressin, Jorg, and Antonio Fatas. 1995. "Regional Labour Market Dynamics in Europe." *European Economic Review,* 39:9, pp. 1627–55.

Dewes, Whaimutu, Tony Walzl, and Doug Martin. 2011. "Owners' Aspirations Regarding the Utilisation of Māori Land." Te Puni Kōkiri, Wellington, NZ. Available online at https://www.tpk.govt.nz/en/a-matou-mohiotanga/land/owners-aspirations-regarding-the-utilisation-of-ma/.

Durie, Mason. 1998. *Te Mana, Te Kāwanatanga: The Politics of Māori Self-Determination.* Auckland, NZ: Oxford University Press.

Fitzgerald, Gerard, C. Nicholas Taylor, and Wayne McClintock. 2002. "The Impacts of Resource Sector Restructuring on Occupational and Community Identity" Paper presented at the Annual Meeting of the International Association for Impact Assessment, Den Haag, The Netherlands, 17–21 June. Available online at http://www.tba.co.nz/pdf_papers/2002_iaia_paper.pdf

Funk, Jason. 2009. "Carbon Farming on Māori Land: Do Governance Structures Matter?" In *Carbon Farming in New Zealand: An Interdisciplinary Assessment of Indigenous Reforestation as a Land-Use System*. San Francisco: Stanford University. Available online at http://motu.nz/our-work/environment-and-resources/lurnz/carbon-farming-on-maori-land-do-governance-structures-matter/.

Grimes, Arthur, and Sean Hyland. 2013. “Passing the Buck: Impacts of Commodity Price Shocks on Local Outcomes.” *Motu Working Paper 13-10.* Motu Economic and Public Policy Research Trust, Wellington, NZ.

Grimes, Arthur, and Chris Young. 2011. “Spatial Effects of ‘Mill’ Closures: Does Distance Matter?” *Australian Journal of Regional Science,* 17:2, pp. 262–97.

Harmsworth, Garth. 2003. “Māori Perspectives on Kyoto Policy: Interim Results. Reducing Greenhouse Gas Emissions from the Terrestrial Biosphere.” Landcare Research. Available online at https://www.landcareresearch.co.nz/__data/assets/pdf_file/0004/43834/maori_perspectives_kyoto_interim.pdf.

Harmsworth, Garth, Marino Tahi, and Chris Karamea Insley. 2010. “Climate Change Business Opportunities for Māori Land and Māori Organisations: Sustainable Land Management Mitigation and Adaptation to Climate Change (SLMACC).” Landcare Research.

Infometrics. 2015. “A General Equilibrium Analysis of Options for New Zealand’s post-2020 Climate Change Contribution.” Report for Ministry for the Environment, Wellington, NZ.

Jaffe, Adam B. 2017. “Barriers to Adoption of No-Cost Options for Mitigation of Agricultural Emissions: A Typology.” *Motu Note 24*. Motu Economic and Public Policy Research Trust, Wellington, NZ. Available online at http://motu.nz/our-work/environment-and-resources/emission-mitigation/agricultural-greenhouse-gas-emissions/barriers-to-adoption-of-no-cost-options-for-mitigation-of-agricultural-emissions-a-typology/.

Kaplan, Greg, and Sam Schulhofer-Wohl. 2017. “Understanding the Long-Run Decline in Interstate Migration.” *International Economic Review,* 58:1, pp. 57–94.

Kerr, Suzi, Simon Anastasiadis, Alex Olssen, William Power, Levente Timar and Wei Zhang. 2012. “Spatial and Temporal Responses to an Emissions Trading Scheme Covering Agriculture and Forestry: Simulation Results from New Zealand.” *Forests*, 3:4, pp. 1133–56. https://doi.org/10.3390/f3041133

Kerr, Suzi, and Alex Olssen. 2012. “Gradual Land-use Change in New Zealand: Results from a Dynamic Econometric Model.” *Motu Working Paper No. 12-06*. Motu Economic and Public Policy Research Trust, Wellington, NZ. Available online at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2061389

Kingi, Tanira. 2004. “Communal Land Tenure and Indigenous Economic Development: Getting the Institutions ‘Right’”. Paper presented at the Aboriginal Land Development Conference, University of Saskatchewan, Saskatoon, Canada. Available online at https://www.researchgate.net/publication/253906664_Communal_Land_Tenure_and_Indigenous_Economic_Development_Getting_the_Institutions_’Right.

———. 2008. “Māori Landownership and Land Management in New Zealand,” in *Making Land Work, Volume 2: Case Studies on Customary Land and Development in the Pacific*, Canberra: Australian Agency for International Development, pp. 129–51. Available online at http://dfat.gov.au/about-us/publications/Documents/MLW_VolumeTwo_CaseStudy_7.pdf

———. 2009. “Māori Land Ownership and Economic Development.” *New Zealand Law Journal,* 10, pp. 396–400.

Kirschbaum, M.U.F. 1999. “CenW, a Forest Growth Model with Linked Carbon, Energy, Nutrient and Water Cycles.” *Ecological Modelling,* 118, pp. 17–59.

Maré, David C, Arthur Grimes, and Melanie Morten. 2009. “Adjustment in Local Labour and Housing Markets.” *Australasian Journal of Regional Studies,* 15:2, pp. 229–48.

McCrostie Little, Heather, and Nick Taylor. 2001. “Social and Economic Impacts Associated with Irrigated Land Use Change” Paper presented to the New Zealand Association for Agricultural and Resource Economics (NZAERS) Conference, Blenheim. Taylor Baines and Associates, Rangiora http://www.tba.co.nz/pdf_papers/2001_nzares.pdf

Mead, Hirini. 2016. *Tikanga Māori (Revised Edition): Living by Māori Values.* Wellington: Huia.

Ministry of Agriculture and Forestry (MAF). 2011. “Māori Agribusiness in New Zealand: A Study of the Māori Freehold Land Resource.” Policy Publications, MAF Policy, Wellington, NZ.

Ministry for the Environment (MfE). 2014. National Policy Statement for Freshwater Management 2014. Wellington, Ministry for the Environment.

Ministry for the Environment (MfE). 2017a. "New Zealand's Greenhouse Gas Inventory 1990–2015: Fulfilling Reporting Requirements under the United National Framework Convention on Climate Change and the Kyoto Protocol." *No. ME 1309*. Wellington, NZ.

Ministry for the Environment (MfE). 2017b. "New Zealand's Seventh National Communication: Fulfilling Reporting Requirements under the United National Framework Convention on Climate Change and the Kyoto Protocol." *No. ME 1340*. Wellington, NZ.

Ministry for the Environment (MfE). 2018a. "New Zealand's Interactive Emissions Tracker." Wellington, NZ. Available online at https://emissionstracker.mfe.govt.nz

Ministry for the Environment (MfE). 2018b. "The Paris Agreement." Available online at http://www.mfe.govt.nz/climate-change/why-climate-change-matters/global-response/paris-agreement

Ministry for Primary Industries (MPI). 2017. "Situation and Outlook for Primary Industries: June 2017." Wellington, NZ. Available online at https://www.mpi.govt.nz/dmsdocument/18443/loggedIn

Molloy, Raven, Christopher L. Smith, and Abigail K. Wozniak. 2014. "Declining Migration within the US: The Role of the Labor Market." National Bureau of Economic Research, Cambridge, MA, USA.

Reid, John. 2011. "Maori Land: A Strategy for Overcoming Constraints on Development." PhD thesis, Lincoln University, Christchurch, NZ. Available online at http://api.digitalnz.org/records/30112596/source.

Reisinger, A., and H. Clark. 2016. "Modelling Agriculture's Contribution to New Zealand's Contribution to the Post-2020 Agreement." *MPI Information Paper No. 2016/02*. Ministry for Primary Industries, Wellington, NZ.

Taylor, Nick, Gerard Fitzgerald and Wayne McClintock. 1999 "Resource community formation and change in New Zealand" Taylor Baines, Rangiora, New Zealand. http://www.tba.co.nz/pdf_papers/1999_issrm.pdf

Timar, Levente. 2011. "Rural Land Use and Land Tenure in New Zealand." *Motu Working Paper No. 11–13*. Motu Economic and Public Policy Research Trust, Wellington, NZ. Available online at http://motu-www.motu.org.nz/wpapers/11_13.pdf

Timar Levente. 2016. "Does Money Grow on Trees? Mitigation under Climate Policy in a Heterogeneous Sheep-beef Sector." *Motu Working Paper 16-09*. Motu Economic and Public Policy Research Trust, Wellington, NZ.

Timar, Levente, and Suzi Kerr. 2014. "Land-use Intensity and Greenhouse Gas Emissions in the LURNZ Model." *Motu Working Paper No. 14–03*. Motu Economic and Public Policy Research Trust, Wellington, NZ. Available online at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2402553

Treasury. 2017. "Pre-election Economic and Fiscal Update 2017." The Treasury, Wellington, NZ. Available online at http://www.treasury.govt.nz/budget/forecasts/prefu2017

West, Graham, Phil Journeaux, Steve Wakelin, and Tanira Kingi. 2016. "Collective Land Tenure Systems and Greenhouse Gas Mitigation among Māori Farmers in Aotearoa, New Zealand." in *Islands of Hope: Pan Pacific Indigenous Resource Management in the Era of Globalisation and Climate Change,* D.D.W. Kuan and P. D'Arcy Eds. Canberra: Australian National University Press. Available online at https://www.researchgate.net/publication/318700638_Collective_land_tenure_systems_and_greenhouse_gas_mitigation_options_among_Maori_farmers_in_New_Zealand

White, Paul I. 1997. "How Do Maori Land Owners Judge Whether the Management of Māori Incorporations Is Successful?" Master's dissertation, Massey University, Palmerston North, NZ. Available online at http://mro.massey.ac.nz/handle/10179/960.