Manaaki Whenua
Landcare Research

Impacts of climate and freshwater policies: Literature Review

Prepared for: Ministry for the Environment

April 2020

Impacts of climate and freshwater policies: Literature Review

Contract Report: LC3697

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Introduction

The New Zealand Government is implementing climate and freshwater policy. These policies will impact decisions on land use and land management. The government is interested in understanding what impact joint climate and freshwater policy will have on nutrient (N and P) losses, sediment loads, net greenhouse gas (GHG) emissions, economic indicators and other relevant indicators. This report summarises, from existing studies, the impact of climate and freshwater policies on climate, freshwater and economic indicators, and other indicators.

Overview of studies

We found seven studies that assessed the impact of joint climate and freshwater policy (Table ES1). An additional 30 studies were identified as related but not directly relevant. Two studies considered the effect of climate policy on freshwater indicators, seven studies considered the effect of freshwater policy on climate indicators, and 22 studies considered the effects of land management on climate and freshwater indicators. One study assessed climate and freshwater policies separately and is included in two categories. All studies focused on impacts in the agricultural sector, and only one study showed impacts on trade.

Joint climate and freshwater policy

Five of the seven studies that jointly assessed climate and freshwater policy were most comparable as they considered similar policy settings. The others differed where one assessed a sediment reduction target on erodible lands (and no nutrient reduction policies) and the other included IPCC climate projection scenarios and had markedly higher GHG prices.

Jointly considering both climate and freshwater policy led to a greater reduction in GHG emissions than either policy in isolation. For those studies with freshwater indicators the joint policies also resulted in a greater reduction in N and P leaching than individual policies. The two studies that tracked sediment and water yield found sediment losses also decreased with climate and freshwater (N targets) policy as did water yield. A reduction in water yield is likely to reduce the amount of water coming from the land that reaches waterways. This reduction in water yield is due to the expansion in forested areas with these policies.

In five studies net revenues decreased between 13–22% depending on the study and the GHG price and/or freshwater target setting. As expected, the biggest decreases in net revenue were from the pastoral land uses. Two studies showed an increase in net revenue—driven by high GHG prices and greater modelled forest productivity in one study and in the other study there was only a carbon payment and no penalty for GHG emissions. In all studies drystock pastoral land uses experienced the greatest reduction in area and forest area increased.

Climate policy

The two climate policy studies, despite different modelling frameworks, showed similar trends. As GHG prices increased, net GHG emissions and N and P losses decreased. For one of the studies (where commodity prices were increasing), the GHG price had to be quite high before it induced conversion away from pastoral land uses to forestry.

Freshwater policy

All studies showed that freshwater policy not only decreased N and P losses but also GHG emissions. Net revenues also decreased. How the freshwater policy was formulated provided some interesting results. For example, if a 10% reduction target was placed on N leaching, then N leaching reduced by 10% but other freshwater indicators (e.g. P loss and *E.coli*) also improved and some times more than the N leaching target level. The study that compared N reduction targets with land management requirements highlighted that stipulating specific suites of land management practices may not achieve the desired reduction in nutrient leaching. This result is further compounded by the effectiveness of practices to reduce nutrient losses or GHG emissions varies spatially and with individual farmer skill levels. In addition, farmers might adopt practices that improve freshwater but continue to intensify production. Therefore, the findings from economic models may overestimate the reductions in freshwater indicators or GHG emissions from policies based on land management requirements.

Land management practice change

Afforestation and on-farm management practices were the focus of most of these studies. Afforestation studies showed improvement in N and P losses, carbon sequestration, biodiversity and net revenues but a reduction in water yield. Note, not all studies included all environmental indicators. On-farm management practice studies showed N mitigation practices reduced GHG emissions substantially more than P mitigation practices.

Caveats

Most identified studies used simulation models to analyse the possible impacts of new policy and/or land management practice changes on climate and freshwater indicators. However, analysing the impacts of policies that have not yet been implemented means assumptions have to be made. Validation of such modelling results is difficult. Building models based on historical trends is also challenging as such policies were not implemented before and we do not know if past choices or decisions will reflect future decisions.

The impacts of climate and freshwater policies will differ across the country in terms of both impacts on profitability and effectiveness of the policies. Therefore, it is not possible to extrapolate the results from a catchment study nationally. Similarly, national results mask any regional differences as a result of a policy.

Climate and freshwater policy will influence land use and management practices, and economic models assume full uptake of management practices (should they be profitable). We know that this is not the case. Therefore, economic modelling results typically overestimate the extent of changes that will occur, especially for policies that target adoption of management practices (as opposed to a specific environmental outcome).

The studies included in this review all differ; there are differences in the questions being answered, the scope and scale of the assessment, policy settings, data sources, sectors covered, biophysical characteristics, and modelling frameworks. Thus, it is challenging to draw robust conclusions from across all studies without first considering the difference between the studies.

The studies in this review focused on economic and ecological modelling of the agricultural sector. No studies were found that assessed the impacts of these policies on the wider economy, impacts on the Māori economy or social impacts.

Table ES1: Joint impacts of climate and freshwater policies

References	Climate policy settings	Freshwater policy settings	Environmental indicators	Scale	Land uses
Daigneault et al. (2012)	GHG prices (2011 NZD): \$25/tCO$_2$e	20% reduction in catchment level N and P leaching	GHG emissions (tCO$_2$e) N leaching (kgN/ha) P leaching (kgP/ha)	Hurunui-Waiau and Manawatu catchments	Dairy, sheep/beef, arable, forestry, scrubland, other pasture, Department of Conservation area
Greenhalgh et al. (2012)	GHG prices (2010 NZD): \$12.5/tCO$_2$e \$25/tCO$_2$e	20% reduction in catchment level N and P leaching	GHG emissions (tCO$_2$e) N Leaching (tN/yr) P Leaching (tP/yr)	Hurunui-Waiau catchments	Dairy, sheep/beef, arable, forestry, scrubland, other pasture, Department of Conservation area
Yeo et al. (2014)	GHG price (2014 NZD): \$25/tCO$_2$e	74% reduction in catchment level N leaching with cap-and-trade scheme	GHG emissions (tCO$_2$e/ha/yr) N Leaching (kgN/ha/yr)	Lake Rotorua catchment	Dairy, sheep/beef, forestry
Daigneault et al. (2018)	GHG prices (2015 NZD): \$10/tCO$_2$e, \$20/tCO$_2$e, \$30/tCO$_2$e	N leaching prices: \$10/kgN, \$20/kgN, \$30/kgN	GHG emissions (tCO$_2$e/yr) Carbon sequestration (tCO$_2$e/yr) N Leaching (tN/yr) P Leaching (tP/yr) Soil erosion (Mt/yr) Water yield (mm/yr)	National (including territorial authority results)	Dairy, sheep/beef, arable, forestry, horticulture, scrubland, native, other (e.g. other pasture)
Ausseil et al. (2019)	GHG prices (2065NZD): \$0, \$288, \$611/tCO$_2$e GHG Prices (2100NZD): \$0, \$1,243, \$2,641/tCO$_2$e	20% reduction in catchment level N and P leaching and sediment load	GHG emissions & Carbon sequestration N Leaching P Leaching Soil erosion (tonnes of soil/km^2/yr)	Kaituna catchment	Dairy, sheep/beef, arable, forestry, horticulture, scrubland, native, other pasture, other non-agriculture (e.g. urban, water)
	The GHG prices are implemented together with IPCC scenarios		Water yield (mm/yr)		
Djanibekov et al. (2019)	GHG prices: \$40/tCO$_2$e (2035NZD), \$50/tCO$_2$e (2050 NZD)	5-m riparian buffers on each side of pastoral farming	GHG emissions (tCO$_2$e/yr) Carbon sequestration (tCO$_2$e/yr)	National (including regional results)	Dairy, sheep/beef, arable, forestry, horticulture, native, other (e.g. urban, water), deer.
	Assessment included: One Billion Trees Programme and the National Environmental Standard for Plantation Forestry				
Neverman et al. (2019)	GHG price (2019 NZD): \$25/tCO$_2$e (applied only to carbon sequestered)	Sediment reduction targets for each catchment	GHG emissions (tCO$_2$e/yr) Carbon sequestration (tCO$_2$e/yr) N Leaching (tN/yr) P Leaching (tP/yr) Soil erosion (t/yr) Following benefits in total \$ over 50 years: water quality, carbon, soil erosion, dredging	National (including regional and catchment results)	Forestry and whole-farm planning as land use mitigations. Other land uses are not specified.

1 Introduction

The Ministry for the Environment is currently assessing the impacts of the Essential Freshwater package as well as climate policy. Any changes to these policies can have significant impacts for New Zealand agriculture, businesses and communities. To understand how climate and freshwater policy interact, the Ministry for the Environment is wanting to build an evidence-base of robust research that has jointly assessed the combined impact of both climate and freshwater policy.

Manaaki Whenua – Landcare Research was commissioned to undertake a systematic literature review of studies that jointly considered climate and freshwater policy. Given the paucity of these studies, we extended the search to include studies that assessed the freshwater benefits of climate policy, studies that assessed the climate benefits of freshwater policy, and studies that focused on land management practices expected to have climate and freshwater benefits.

The objectives of the report are to:

a identify and summarise from existing studies the impact that joint climate and freshwater policy has on climate and freshwater indicators

b summarise from these studies any impacts on the environment, industry, social, Māori economy, and regional councils due to climate policy and freshwater policy.

The report provides details on how the literature review was undertaken, summarises the key messages from each category of studies and provides an overview of findings from the individual joint climate and freshwater policy studies. The appendices provide a brief summary of the results of all studies included in the review.

2 Methods

A targeted systematic literature review was carried out using Google Scholar, ISI Web of Science and Scopus. Additional searches were performed using the Ministry for the Environment, Ministry for Primary Industries, Department of Conservation, AgResearch, NIWA, Plant & Food, and Deep South National Science Challenges websites. Based on expert discussions, five regional council websites (Waikato, Canterbury, Horizons, Wellington and Southland) were also searched for reports they may have contracted that could be relevant. Experts in the fields of climate and freshwater policies were also contacted and asked to provide relevant research.

Similar to Cradock-Henry (2020), we designed a three-stage process for literature selection and screening. The search terms were compiled to capture the full range of research outputs associated with climate and freshwater policies. We used search terms "climate" OR "climate policy" OR "climate change mitigation" OR "GHG" OR "GHG emissions" AND "water" OR "freshwater policy" OR "nutrients" OR "sediment" OR "Nitrogen" OR "Phosphorous" OR "E. coli" AND "New Zealand". Based on search terms used for literature search, we classified the studies into four groups:

- studies that jointly considered both climate and freshwater policies,

- studies that looked at the freshwater benefits of climate policy,
- studies that looked at the climate benefits of freshwater policy,
- studies that focused on land management practices (e.g. afforestation) that are expected to have climate and freshwater benefits.

For climate indicators, we considered greenhouse gas (GHG) emissions and carbon sequestration. For freshwater indicators, we considered nutrient (nitrogen (N) and phosphorous (P)) leaching, sediment load and E. coli. We have identified policy scenarios as limits or prices on considered freshwater or climate indicators, whereas practices are individual or bundled changes to agricultural practice with the aim of reducing freshwater indicators or GHG emissions or increasing carbon sequestration.

Table 1 outlines the inclusion/exclusion criteria used to ensure the search returns were fit for the specified purpose of our review. A range of different types of publications were included if deemed relevant, including academic journal articles and grey literature (ministry reports, regional council reports, conference proceedings and working papers).

Table 1: Article screening criteria

Included	Excluded
Peer-reviewed journals, research reports, conference proceedings, book chapters	Non-scientific articles and materials
Published studies (even for internal purposes)	Non-published studies (i.e. drafts were excluded)
Having joint analysis on climate and freshwater policies and/or outputs	Having only impacts of single policy (i.e. climate or freshwater policy) and/or direct impacts on environmental indicators (e.g. climate policy on climate indicators)
Agricultural and forestry land uses	Health, psychological and other non-land use related studies
For climate policy we considered GHG indicators	Impacts related to weather policies (e.g. weather insurance) are not included
Have empirical and/or modelling results	Theoretical studies
Research that was published once	Studies that were published several times in different forms were not considered (e.g. excluding studies that were first published as a conference proceeding then as a journal article)
Written in English	Non-English work (the project timeframe and budget does not enable us to look for Māori language studies)
Must relate to New Zealand	Not related to New Zealand context

The screening steps clarify the robust and repeatable process used to remove irrelevant and duplicate returns from the search outputs (Table 2).

Table 2: Screening procedure

Screening steps
Searches were conducted using search terms and duplicates removed
Review the publications titles and remove publications that do not meet criteria
Read abstract/conclusions and scan publication, and remove publications that do not meet criteria
Returns were classified into four groups (noted above)

During the literature review process, we encountered numerous publications that analysed different settings for climate and freshwater policy (e.g. Daigneault et al. 2019; Djanibekov & Samarasinghe 2019). However, these studies only considered the target environmental indicators, e.g. the climate policy studies only considered the impact on GHG emissions. These publications were excluded. There were also several publications based on theoretical research that looked at multiple policies (e.g. Yeo & Coleman 2014). These publications were also excluded.

3 Results

3.1 Overview of studies

Through the literature review we found 7 studies that focused on the central topic of our literature review search, the joint implementation of climate and freshwater policies. We have also included 30 additional studies that do not jointly implement both policies, but still meet our search criteria (see **Error! Reference source not found.**). Of the 37 total publications:

- 7 jointly considered climate and freshwater policies (Table 3),
- 2 considered the effect of climate policy on freshwater indicators (Table 4),[1]
- 7 considered the effect of freshwater policy on climate indicators (Table 5),
- 22 focused on the effects of land management on freshwater and climate indicators (Table 6).

One publication included two separate analyses: first analysing climate policy and then independently analysing freshwater policy. Therefore, it is included in two different study categories, i.e. in climate policy and freshwater policy categories (see Daigneault et al. 2011).

The land management studies focused on the effects of on-farm management practices (e.g. change in stocking rate, use of nitrification inhibitor DCD), expansion of afforestation and the improvement of agriculture infrastructure (e.g. establishment of irrigation canals) on climate and freshwater indicators. Four of the land management studies focused on the valuation of ecosystem services from changes in farm management practices. For a more detailed list of the publications see Appendixes 1–4.

Comparison between the studies is challenging. Therefore, caution is needed when drawing conclusions from across multiple publications. Careful attention should be given to the underlying assumptions as these affect the results. Even if the same catchment is the focus of two publications (e.g. Hurunui-Waiau catchment) or they used similar tools (e.g. simulation models) the studies all differ. They differ in parameters such as scope and scale of research, policy settings (and policy scenario included into the modelling), data sources, sectors covered, biophysical characteristics (e.g. whether Land Use Capability or soil type was considered), outputs and modelling framework.

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[1] We included Daigneault et al. (2011) in two different study categories, i.e. in climate policy and freshwater policy category, because the study independently analysed first climate policy and then freshwater policy.

All identified policy publications include climate and freshwater indicators:

- 1 joint study used price only to represent climate and freshwater policy, i.e. GHG and N prices,
- 6 joint policy studies used a mix of prices and targets, i.e. GHG prices and nutrient (N and/or P) and/or sediment reduction targets,
- 2 climate policy studies used GHG prices,
- 7 freshwater policy studies used nutrient (N and/or P) and/or sediment reduction targets,
- 1 land management policy study used riparian buffers to represent freshwater policy,
- 6 land management policy studies focused on afforestation and its co-benefits for climate and freshwater indicators,
- 10 land management policy studies analysed the impacts of change in on-farm management practices on climate and freshwater indicators,
- 4 land management policy studies valued the change in ecosystem service provision from a change of on-farm management practices,
- 1 land management policy study focused on environmental efficiency of farming using GHG, N and P leaching and economic indicators as determinants of efficiency.

The scale and scope of analysis of the publications differed:

- 16 studies were national level analyses. Most of these studies also provided results at the regional, territorial authorities, or catchment level, or at 25km^2 grids,
- 6 studies were at the regional level,
- 13 studies were at the catchment scale,
- 2 studies were at the farm-level.

Most studies used simulation (e.g. optimisation, behavioural agent-based, ecological forecast) models to analyse the possible impacts of policy and/or land management changes on climate and freshwater indicators. Simulation models are useful to understand the change in the analysed system (e.g. agriculture and forestry production at the national, catchment, or farm levels) from implementing new policies and/or practices. At the same time, this can be a disadvantage because analysing the impacts of policies that have not yet been implemented means assumptions have to be made. Validation of modelling results of new policy settings is always difficult. Building models based on historical trends is also challenging as we do not know if past choices or decisions will reflect future decisions.

Of the 9 studies that used GHG prices, 7 studies[2] found that pastoral area (primarily drystock) converted to lower intensity uses, mostly forestry. This led to a corresponding decrease in GHG emissions, N and P leaching and net revenue (from agriculture and forestry). In contrast, the other 2 studies[3] using GHG prices found GHG emissions reduced but net revenues

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[2] See Daigneault et al. (2011; 2012; 2018), Djanibekov et al. (2019), Greenhalgh et al. (2012), Morgan & Daigneault (2015), Yeo et al. (2014).

[3] See Ausseil et al. (2019), Neverman et al. (2019).

increased. The increase in net revenues of one of the studies came from an increase in projected dairy and forestry net revenues, while increase in net revenues of another study is due to having the carbon sequestration payments and not considering GHG emission prices for agricultural activities.

Seven studies[4] assessed the impacts of freshwater policy and used nutrient and/or sediment reduction targets to represent policy. Of these, 4 studies[5] found that net revenues and GHG emissions declined. However, one study[6] found decrease in GHG emissions, while the net revenues increased due to that farmers trade their allocated permits for N and P. The remaining two freshwater policy studies[7] did not present results on net revenues. In all studies carbon sequestration increases.

Six of the 22 land management practice studies assessed the impact of afforestation. All afforestation studies found net revenue increased due to different benefits. Soil erosion, GHG emissions, nutrient leaching and water yield reduced, while carbon sequestration and biodiversity increased with afforestation.

Studies that include native forest, often do not include its value or only include its production potential or partial benefits. Valuing the diverse benefits of native forest, e.g. biodiversity and cultural benefits, are difficult to quantify. This means that the studies rarely show expansion of native forestry unless through an assumption dictating this land use change.

It is challenging with the land management studies to make many generalisations as the underlying assumptions and approaches were quite different.

In the following section, we describe in detail the 7 studies that jointly considered climate and freshwater policy. We include a summary of each studies and outline the key similarities between the studies. Subsequent publication groupings do not summarize the findings from the individual studies.

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[4] See Daigneault et al. (2011; 2013; 2017a), Duhon et al. (2015), MfE (2019), Samarasinghe et al. (2011), Strutt & Rae (2011).

[5] See Daigneault et al. (2013; 2017a), Samarasinghe et al. (2011), Strutt & Rae (2011).

[6] See Daigneault et al. (2011).

[7] See Duhon et al. (2015), MfE (2019).

Table 3: Joint impacts of climate and freshwater policies

References	Climate policy settings	Freshwater policy settings	Environmental indicators	Scale	Land uses
Daigneault et al. (2012)	GHG prices (2011 NZD): \$25/tCO$_2$e	20% reduction in catchment level N and P leaching	GHG emissions (tCO$_2$e) N leaching (kgN/ha) P leaching (kgP/ha)	Hurunui-Waiau and Manawatu catchments	Dairy, sheep/beef, arable, forestry, scrubland, other pasture, Department of Conservation area
Greenhalgh et al. (2012)	GHG prices (2010 NZD): \$12.5/tCO$_2$e \$25/tCO$_2$e	20% reduction in catchment level N and P leaching	GHG emissions (tCO$_2$e) N Leaching (tN/yr) P Leaching (tP/yr)	Hurunui-Waiau catchments	Dairy, sheep/beef, arable, forestry, scrubland, other pasture, Department of Conservation area
Yeo et al. (2014)	GHG price (2014 NZD): \$25/tCO$_2$e	74% reduction in catchment level N leaching with cap-and-trade scheme	GHG emissions (tCO$_2$e/ha/yr) N Leaching (kgN/ha/yr)	Lake Rotorua catchment	Dairy, sheep/beef, forestry
Daigneault et al. (2018)	GHG prices (2015 NZD): \$10/tCO$_2$e, \$20/tCO$_2$e, \$30/tCO$_2$e	N leaching prices: \$10/kgN, \$20/kgN, \$30/kgN	GHG emissions (tCO$_2$e/yr) Carbon sequestration (tCO$_2$e/yr) N Leaching (tN/yr) P Leaching (tP/yr) Soil erosion (Mt/yr) Water yield (mm/yr)	National (including territorial authority results)	Dairy, sheep/beef, arable, forestry, horticulture, scrubland, native, other (e.g. other pasture)
Ausseil et al. (2019)	GHG prices (2065NZD): \$0, \$288, \$611/tCO$_2$e GHG Prices (2100NZD): \$0, \$1,243, \$2,641/tCO$_2$e The GHG prices are implemented together with IPCC scenarios	20% reduction in catchment level N and P leaching and sediment load	GHG emissions & Carbon sequestration N Leaching P Leaching Soil erosion (tonnes of soil/km^2/yr) Water yield (mm/yr)	Kaituna catchment	Dairy, sheep/beef, arable, forestry, horticulture, scrubland, native, other pasture, other non-agriculture (e.g. urban, water)
Djanibekov et al. (2019)	GHG prices: \$40/tCO$_2$e (2035NZD), \$50/tCO$_2$e (2050 NZD) Assessment included: One Billion Trees Programme and the National Environmental Standard for Plantation Forestry	5-m riparian buffers on each side of pastoral farming	GHG emissions (tCO$_2$e/yr) Carbon sequestration (tCO$_2$e/yr)	National (including regional results)	Dairy, sheep/beef, arable, forestry, horticulture, native, other (e.g. urban, water), deer.
Neverman et al. (2019)	GHG price (2019 NZD): \$25/tCO$_2$e (applied only to carbon sequestered)	Sediment reduction targets for each catchment	GHG emissions (tCO$_2$e/yr) Carbon sequestration (tCO$_2$e/yr) N Leaching (tN/yr) P Leaching (tP/yr) Soil erosion (t/yr) Following benefits in total \$ over 50 years: water quality, carbon, soil erosion, dredging	National (including regional and catchment results)	Forestry and whole-farm planning as land use mitigations. Other land uses are not specified.

Table 4: Climate policy

References	Climate policy settings	Freshwater policy settings	Scale	Land uses
Daigneault et al. (2011)	GHG prices (2015NZD): \$20, \$40/tCO_2e		Hurunui-Waiau catchments	Dairy, sheep/beef, arable, forestry, scrubland, other pasture (pigs), Department of Conservation area, deer
Morgan & Daigneault (2015)	GHG prices (2011 NZD): \$0, \$20, \$40, \$60/tCO_2e		Hurunui-Waiau catchments	Dairy, sheep/beef, forestry

Table 5: Freshwater policy

References	Climate change policy settings	Freshwater policy settings	Scale	Land uses
Daigneault et al. (2011)[8]		Cap N and P at current levels. Trade of N and P allocated permits	Hurunui-Waiau catchments	Dairy, sheep/beef, arable, forestry, scrubland, other pasture (pigs), Department of Conservation area, deer
Samarasinghe et al. (2011)		15%, 30 % N and P reduction targets	Hurunui catchment	Dairy, sheep/beef, arable, forestry, horticulture, native, other (e.g. urban, water), deer
Strutt & Rae (2011)		10%, 20%, 30% N reduction target	National	Dairy
Daigneault et al. (2013)		45% reduction in N leaching	Hinds Catchment	Dairy, sheep/ beef, arable, Horticulture, Forestry, Native
Daigneault et al. (2017a)		Varying targets for N, P and *E. coli* by council	National (including regional and catchment results)	Dairy, sheep/beef, arable, forestry, horticulture, native, other (e.g. urban, water), deer
Duhon et al. (2015)		20% reduction in N through cap/trade	Lake Taupo	Dairy, sheep/beef
MfE (2019)		Streamside planting (to reduce rural runoff), retention of more natural wetlands, and potentially less intensive stocking	National	Dairy, sheep/beef, arable, forestry, horticulture, other (e.g. urban, water), deer

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[8] There is another paper with a similar title by these authors. We have chosen the latest version of this conference paper from the Agricultural & Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting. The results from this version are different than those of earlier versions due to a difference in catchment productivity.

Table 6: Land management practice studies

Reference	Practice	Scale	Land uses
Riparian			
Daigneault et al. (2017b)	Riparian Buffer (5m, 10m, 20m, 50m)	National (including territorial authority results)	Dairy, sheep/beef, arable, horticulture, forestry, native, other land uses (e.g. urban, water)
Afforestation			
Dymond et al. (2012)	Afforestation	National	Low productivity land
Ausseil et al. (2013)	Afforestation	Manawatu catchment	Dairy, sheep/beef, forestry, deer
Monge et al. (2016)	Afforestation	Farm level (dairy farm in Rotorua)	Dairy
Dymond et al. (2013)	Afforestation (Indigenous)	National	Pasture, scrublands
Walsh et al. (2017)	Afforestation	National and Manawatu catchment	Dairy, sheep/beef, arable, horticulture, forestry, native, other land uses (e.g. urban, water), deer, pig, other pasture
Walsh (2019)	Afforestation (from exotic to native forestry)	Gisborne	Exotic forestry, indigenous forestry
Individual on-farm management practices			
Monaghan et al. (2008)	Best management practices (optimum soil Olsen P level, deferred effluent irrigation, applying small amounts of effluent, Low rate effluent irrigation, bundling, low solubility P fertiliser, nitrification inhibitor, inclusion of low N feed in diet, low N input, restrict autumn/winter grazing, covered wintering pads, advanced pond system	National	Dairy
Anastasiadis & Kerr (2013)	Farm management	National	Dairy
Doole & Romera (2015)	Stand-off pad	Farm level (Waikato)	Dairy
Vibart et al. (2015)	Improved nutrient management, Improved animal productivity and restricted grazing	Southland	Dairy, Sheep/beef
Lou (2017)	N leaching management	National	Dairy, Sheep/beef

Reference	Practice	Scale	Land uses
Bundles of on-farm management practices			
Wilcock et al. (2008)	Afforestation, riparian, N budgeting, waste treatment technology	National	Dairy, sheep/beef
Daigneault and Elliot (2017)	Bundles (cost effective measures, less cost effective with large capital costs, large cost and unproven)	National	Dairy, sheep/beef, deer, arable, horticulture
Matheson et al. (2018)	Bundles (low cost and low barrier to adoption, moderate barrier and direct cost, and high barrier and high cost	Kaituna-Pongakawa-Waitahanui and Randitaiki Water Management Area	Dairy, drystock, arable, kiwifruit and forestry
Intensification of agricultural land			
Vogeler et al. (2014)	Dairy Intensification	Southland	Dairy
Foote et al. (2015)	Dairy Intensification	National	Dairy
Economic valuation studies of ecosystem services			
Baskaran et al. (2009a)	10% and 30% reduction in methane emissions; 10% and 30% reduction in N Leaching; 10% and 30% reduction in water usage for in irrigation	Canterbury	Dairy
Baskaran et al. (2009b)	10% and 30% reduction in methane emissions; 10% and 30% reduction in N Leaching; 10% and 30% reduction in water usage for in irrigation	Canterbury	Pastoral
Takatsuka et al. (2009)	50% reduction in GHG emissions, 20% reduction in N leaching	National	Arable
Baskaran et al. (2010)	30% reduction in GHG emissions, 0 GHG emissions/ha, removal of toxic chemic residue from groundwater	Hawkes' Bay, Marlborough	Viticulture
Other			
Soliman & Djanibekov (2018)	GHG, N and P leaching and economic efficiencies of farm management and agro-ecological conditions	Waikato/Bay of Plenty, Canterbury, Lower North Island, Northland, Southland, Taranaki	Dairy

3.2 Joint climate and freshwater policy studies

We found 7 studies that jointly considered climate and freshwater policies (see **Error! Reference source not found.**)**Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.**. Of these, 5 are in the field of economics (Daigneault et al. 2012 2018; Djanibekov et al. 2019; Greenhalgh et al. 2012; Yeo et al. 2014), and 2 use integrated and interdisciplinary approaches (Ausseil et al. 2019; Neverman et al. 2019). 3 focused on the entirety of New Zealand, while disaggregating the analysis by regions/territorial authorities/catchments, and the remaining 4 focused on catchments.

Description of objectives and methods

The main study objectives of the 7 studies were to estimate the impacts of introducing climate and freshwater policies on land use, net revenues and environmental outputs. Only the work by Ausseil et al. (2019) set the main objective as analysing the impacts of climate change projections using the climate change trajectories of the Intergovernmental Panel on Climate Change (IPCC) and adaptation/mitigation developments. The study included also nutrient and sediment reduction targets as complimentary policy to reflect New Zealand's freshwater policy.

Daigneault et al. (2012) and Greenhalgh et al. (2012) mainly focused on analysing the impacts of different GHG prices (for both carbon sequestration and agricultural emissions) as well as a 20% nutrient leaching target on land use change, net revenues and GHG and nutrient leaching outputs. Both studies conducted a catchment level analysis. Daigneault et al. (2018) analysed the impacts of different GHG and N leaching prices on land use change, net revenues and GHG and nutrient leaching outputs.

Yeo et al. (2014) analysed the impacts of implementing N trading and GHG price policies on dairy, sheep and beef and forestry areas, net revenues, GHG emissions and nutrient leaching in the Lake Rotorua catchment. In the N trading scheme they considered auctioning (i.e. regional council owning the N leaching permit levels and selling to farmers), free allocation (i.e. farmers receive optimal level of allowed N leaching for free) and grandfathering (i.e. farmers are granted N leaching levels based on their baseline levels and the regional council buys back the N leaching permit levels up to the optimal level of N) schemes to meet the N leaching target.

Djanibekov et al. (2019) estimated the projected impacts of different agro-environmental policies on land use change, net revenues, livestock number, GHG emissions and carbon sequestration. These policies include GHG prices, freshwater policy (by establishing riparian buffers on livestock farms), the One Billion Tree programme, and the National Environmental Standard for Plantation Forestry. In this study, the combination of climate and freshwater policies were considered together with other agro-environmental policies. Djanibekov et al. (2019) did not present physical outputs contributing to freshwater (e.g. nutrient leaching, sediment, *E.coli*) but analysed the impact of the policy on land use, net revenues and GHG emissions.

Daigneault et al. (2012; 2018), Djanibekov et al. (2019), Greenhalgh et al. (2012) and Yeo et al. (2014) analysed each policy individually as well as in combination with climate and freshwater policies.

The study by Neverman et al. (2019) focused on sediment reduction and analysed the impacts of imposing sediment reduction targets in catchments across New Zealand, while accounting for the carbon sequestration price to reflect the existing Emissions Trading Scheme (ETS). This study assessed the effects of sediment reduction targets on the adoption of on-farm mitigations, net revenues, environmental outputs and co-benefits. These highlighted differences reveal diverse policy settings, but also make comparison among policies challenging.

With the exception of Neverman et al. (2019), which did not specify land uses, these studies considered major land uses and analysed land use change. In addition to land use change, all studies considered different land management practices (e.g. change in stocking and fertiliser rates, establishment of farm woodlots). However, only the study by Neverman et al. (2019) presented the results by management practices, where they included establishment of woodlots (afforestation) and whole-farm planning practices. The remaining 6 studies considered land management practices in their analysis but did not explicitly present their results. Having both land use and management practice changes might reduce the negative impacts of policies on farmers and achieve better environmental objectives. Farmers are likely to change their farm management practices before the land use change.

The studies differed in the land uses and environmental outputs they considered (see Table 3). Most studies included net GHG emissions (sequestration and emissions) and freshwater indicators; Djanibekov et al. (2019) was the exception. Ausseil et al. (2019) and Daigneault et al. (2018) also included sediment losses and water yield as environmental indicators.

Only the study by Neverman et al. (2019) estimated the economic (monetised and discounted) co-benefits from having climate (GHG prices for carbon sequestered) and freshwater (sediment reduction) policies. They considered the co-benefits of the combined policies such as the avoided costs of dredging and sediment, and the returns from carbon (both increase in carbon sequestration and changes in GHG emissions) and water clarity. Including the various co-costs and co-benefits into the analysis estimates the policy effects on a wider suite of environmental indicators.

None of the studies included any assessment of the wider economic impacts (e.g. impacts on employment or GDP) of climate and/or freshwater policy.

Joint climate and freshwater policy studies: Summary

The most comparable studies are Daigneault et al. (2012), Greenhalgh et al. (2012), Yeo et al. (2014), Daigneault et al. (2018), and Djanibekov et al. (2019) as the policy scenarios in these studies were similar. These studies also included similar land uses and used a similar economic land use modelling framework, except Yeo et al. (2014) who only included sheep and beef, dairy and forestry and used a different model construct. Djanibekov et al. (2019) did not include freshwater indicators. Therefore, it is not possible to determine how joint policy affects freshwater in this study.

Neverman et al. (2019) differed from the other studies in that they only looked at a sediment target applied to land classified as erodible and their climate policy was a payment for sequestered carbon. No price was applied to GHG emissions. Thus, it is not comparable to the other studies.

Ausseil et al. (2019) differed as they included changes in climate in line with the IPCC climate projection scenarios. Their projected GHG price was also much higher than the other studies.

A summary of the findings from each of these studies can be found in Appendix 1. A more detailed discussion of the results is found in the section on the summary of individual studies.

Land use change

With the exception of Djanibekov et al. (2019), the studies showed that joint climate and freshwater policy reduced the area of sheep and beef the most followed by dairy, with pastoral land switching to forestry.

Djanibekov et al. (2019), while showing similar land use change trends, found deer area decreased the most followed by sheep and beef, other pasture and dairy. This finding is derived from Djanibekov et al. (2019) explicitly including deer as a separate land use; the other studies did not.

In Yeo et al. (2014) all sheep and beef land in the Rotorua catchment converted to forestry while dairy land remained in dairy under the combined climate and freshwater policy. The result is likely driven by the carbon sequestration payment, which made forestry become more profitable than sheep and beef. Dairy, however, remained the most profitable land use in the catchment.

Neverman et al. (2019), while different to the other studies, did show a decrease in pastoral land area and there was a corresponding increase in forest area.

Net revenue

In the five most directly comparable studies (Daigneault et al. 2012, Greenhalgh et al. 2012, Yeo et al. 2014, Daigneault et al. 2018, Djanibekov et al. 2019) net revenues decreased with joint climate and freshwater policy. Net revenue decreased between 13–22% depending on the study and the GHG price and/or freshwater target setting. As expected, the biggest decreases in net revenue were from the pastoral land uses.

The results from Ausseil et al. (2019) and Neverman et al. (2019) differed as they found that net revenue increased. In Ausseil et al. (2019) the increase in net revenue comes from the projected increase in forestry net revenues (based on high GHG prices and greater forest productivity). These increases were greater than the costs associated with agricultural emissions and the actions taken to reduce N and P leaching and sediment loads by 20%. Neverman et al. (2019) only considered a carbon payment and there was no penalty for GHG emissions which likely drives this result.

Environmental outputs

Daigneault et al. (2012; 2018), Djanibekov et al. (2019) and Greenhalgh et al. (2012) found that jointly considering both climate and freshwater policy led to a greater reduction in GHG emissions than either policy in isolation. Similarly, except for Djanibekov et al. (2019), the joint policies resulted in a greater reduction in N and P leaching than individual policies; Djanibekov does not include freshwater indicators. Yeo et al. (2014) showed a similar result in that joint climate and freshwater policy reduced N leaching and net GHG emissions more than the policies individually.

Both sediment and water yield were also tracked in Ausseil (2019) and Daigneault et al. (2018). This study highlighted that while sediment losses also reduced with climate and freshwater (N targets) policy so did water yield. A reduction in water yield is likely to reduce the amount of water coming from the land that reaches waterways. This reduction in water yield is due to the expansion in forested areas with these policies.

Economic co-benefits

Neverman et al. (2019) included dredging costs in their study. A sediment reduction target and carbon sequestration payment reduced sediment losses, which subsequently reduced dredging costs. Monetary benefits of improved water clarity were also noted.

Caveats

The caveats for each study are described in the relevant sections below. These caveats should be read carefully as they could provide greater clarity for why some studies have certain results.

Summary of individual studies

1) Publication by Daigneault et al. (2012)

This study used the New Zealand Forest and Agriculture and Regional Model (NZFARM), to analyse the impacts of GHG prices and nutrient leaching reduction target policies on land use allocation, net revenues, and agricultural and environmental outputs. The study focused on the Hurunui–Waiau and Manawatu catchments and considered major land uses. The authors analysed the possible impacts of introducing GHG prices of \$25/tCO_2e and 20% N and P leaching reduction target on land uses. The GHG price and nutrient leaching reduction target were analysed both separately and in combination. The GHG price is imposed as levies for all analysed land uses that emit GHG, and as a payment for carbon sequestration in forestry. The results of simulated GHG price and nutrient leaching reduction target were presented against the baseline situation, where it was assumed that there is no agro-environmental policy present except credits given to forestry activities for carbon sequestration.

Caveats

The study relies on Lincoln University's Financial Budget Manual, MPI's farm monitoring report, and other reports. These sources might not properly reflect the observed farm budgets. Also, the study considered GHG emissions, carbon sequestration and nutrient leaching and did not consider other environmental outputs such as water yield, which can reduce from the expansion of forestry area.

Results

The combination of a GHG price and a nutrient leaching reduction target reduces areas of sheep and beef (11%) and dairy (2%) in the Hurunui-Waiau catchment (Figure 1). Instead, the areas of forestry (7%), arable (2%), other pasture (2%) and scrubland (2%) increase in the catchment. In the Manawatu catchment, the areas of sheep and beef (17%) and dairy (5%) reduce, while the areas of forestry (3%), scrubland (4%) and other pasture (2%) increase.

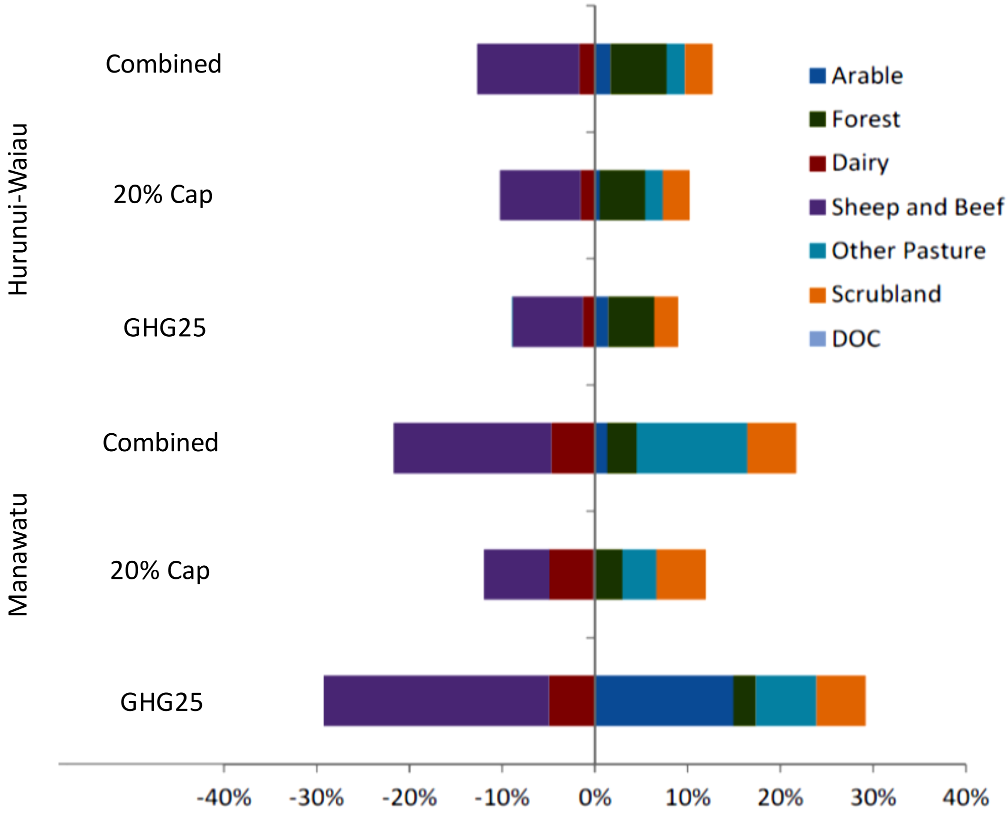


Figure 1: Relative change from the baseline of land use area, in % per year.

The Hurunui-Waiau catchment can achieve larger GHG emission reduction at a lower cost than in the Manawatu catchment (Table 7). In the GHG only price scenario (GHG25), the summed agricultural and forestry net revenues reduce in the Hurunui-Waiau (13%) and Manawatu (20%) catchments. With only a 20% nutrient leaching reduction (20% Cap) the summed net revenues from land uses reduce in the Hurunui-Waiau (5%) and Manawatu (1%) catchments. In the scenario that combines both GHG price and nutrient leaching target reduction, the summed net revenues from all land uses reduce in the Hurunui-Waiau (15%) and Manawatu (21%) catchments.

Table 7: Relative change from the baseline of key outputs, in % per year

Policy scenarios	Net revenues	Total GHG emissions	N leaching	P loss
		Hurunui-Waiau		
GHG25	–13	–26	–11	–6
20% Cap	–5	–22	–20	–20
Combined	–15	–34	–20	–20
		Manawatu		
GHG25	–20	–40	–55	–38
20% Cap	–1	–16	–20	–20
Combined	–21	–32	–20	–20

2) Publication by Greenhalgh et al. (2012)

This study used the NZFARM model to analyse the impacts of GHG prices and nutrient leaching reduction targets on land use allocation, net revenues, and agricultural and environmental outputs. The study area is the Hurunui–Waiao catchment and considered major land uses. The study analysed the possible impacts of GHG prices ($12.5 (GHG12.50) and $25/tCO$_2$e (GHG25)) and a 20% N and P leaching reduction target (20% Cap). The GHG prices and nutrient leaching reduction target were analysed as stand-alone policies and in combination (Combined12.50; Combined25). The GHG prices are imposed as levies for all analysed land uses that emit GHG, and as a payment for carbon sequestration in forestry. The results of the simulated GHG prices and nutrient leaching reduction target were presented against the baseline situation, where it was assumed there is no agro-environmental policy present except for credits given to forestry activities for carbon sequestration.

Caveats

The study considered GHG emissions, carbon sequestration and nutrient leaching, and did not consider other environmental outputs such as water yield, which can reduce from the expansion of forestry.

Results

Introducing a stand-alone GHG price of $25/tCO$_2$e reduces the area of sheep and beef more than a stand-alone nutrient reduction policy, while the opposite holds true for dairy and other pasture (Table 8). The combination of a GHG price and a 20% nutrient leaching reduction target reduces sheep and beef (8%) and dairy (2%) areas , while areas of forestry (5%), arable (1%) and scrubland (4%) increase.

Table 8: Relative change from the baseline of land use area, in % per year

Land use	GHG12.50	GHG25	20% Cap	Combined12.50	Combined25
Arable	0.5	1.2	0.1	0.6	0.9
Forestry	1.6	4.3	4.0	4.5	5.0
Dairy	–0.3	–1.1	–1.3	–1.3	–1.5
Sheep/beef	–2.3	–6.4	–6.0	–6.8	–8.0
Other pasture	0	–0.1	–0.3	–0.2	–0.2
Scrubland	0.6	2.1	3.5	3.3	3.6

In the GHG price scenario ($25/tCO$_2$e), the summed agricultural and forestry net revenues reduce by 14% (Figure 2). With only a 20% nutrient leaching cap, the summed net revenues from the land uses reduce by 4%. In the scenario that combines both a GHG price and a nutrient leaching cap, the summed net revenues from all land uses reduce by 17%.

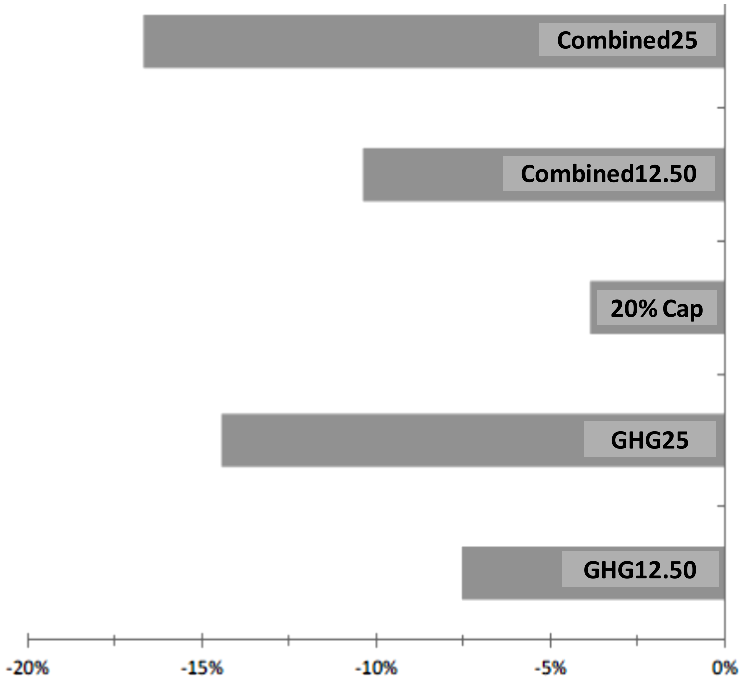


Figure 2: Relative change from the baseline of net revenues, in % per year.

The combination of a GHG price and a nutrient leaching reduction target (Combined12.50 and Combined25) leads to the largest reduction levels of net GHG emissions and gross GHG emissions, because this scenario has lower pastoral area and larger forestry area than the stand-alone policies (Figure 3). The stand-alone 20% nutrient leaching target reduces GHG emissions more than the stand-alone GHG price scenarios.

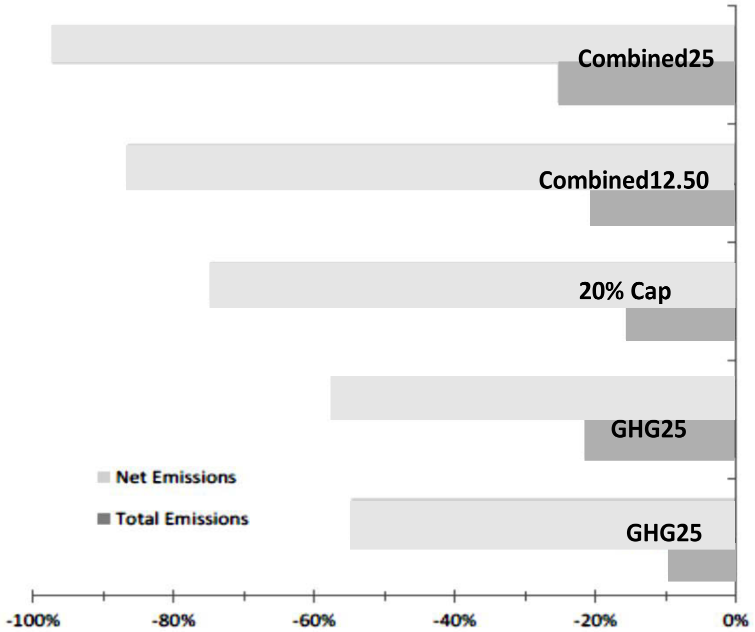
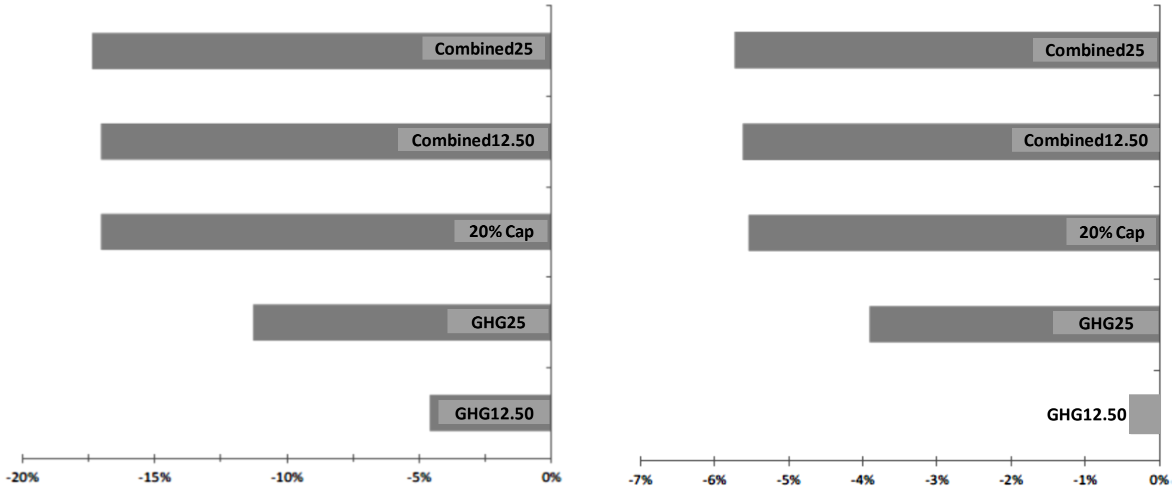


Figure 3: Relative change from the baseline in GHG emissions, in % per year.

The combination of a GHG price and a 20% nutrient reduction target leads to the largest N and P leaching reduction levels (**Error! Reference source not found.**).



(a) **(b)**

Figure 4: Relative change from the baseline in N (a) and P (b) leaching, in % per year.

3) Publication by Yeo et al. (2014)

The study analysed the impacts of jointly introducing a GHG price (carbon sequestration payment) and N cap and trade scheme (i.e. GHG price of \$25/ tCO_2e and N trading) for dairy and sheep and beef land uses. The study tracked net revenue, GHG emissions and N leaching. The authors used NManager, which incorporated farm profits into a catchment level hydrology model. In the N trading scheme, the authors considered auctioning (i.e. regional council owning the N permits (i.e. discharge allocations) and selling them to farmers), free allocation (i.e. farmers receive optimal level of allowed N leaching for free) and grandfathering (i.e. farmers are granted N leaching discharge allowances based on their baseline N leaching levels and the regional council buys back the allowances up to the optimal level of N). The N trading scenario's N leaching reduction target was set at the regional council N runoff target for Lake Rotorua. This reduction target was to reduce N leaching 74% below the current N load in the lake, which equated to the regional council's target N load of 435 t. The GHG price of \$25/tCO$_2$e (scenario GHG25) only considers payments for carbon sequestered through forestry. The GHG payments were assumed to come under the Emissions Trading Scheme (ETS) and have fixed value in the model. The N leaching permit price was estimated endogenously by the model and its value was not presented in the study.

Caveats

A limitation of the study is that it assumed homogeneous dairy and sheep and beef farms. This may underestimate (or overestimate) the gains from using a trading scheme since it means that there is no potential for trade between farms on the same land use type that have varying abatement costs. In addition, the study did not consider other environmental indicators.

Results

The three policies have different impacts on the areas of each land use modelled – forestry, dairy and sheep and beef (Figure 5). When only a GHG price is included, there is no change in land use area. Under the N trading scenario, all dairy is either converted to sheep and beef or forestry as dairy leaches more N than the other land uses and the N reduction target is large. However, in the combined policy scenario dairy area is unchanged, while all sheep and beef convert to forestry. In this scenario the price of N permits falls due to the addition of the ETS, making dairy viable and there is no need to convert from dairy to a lower N leaching land use. Sheep and beef farmers on the other hand convert to forestry. Forestry is now more profitable with the additional revenue generated through the ETS while the profitability of sheep and beef decreases with the N permit price.

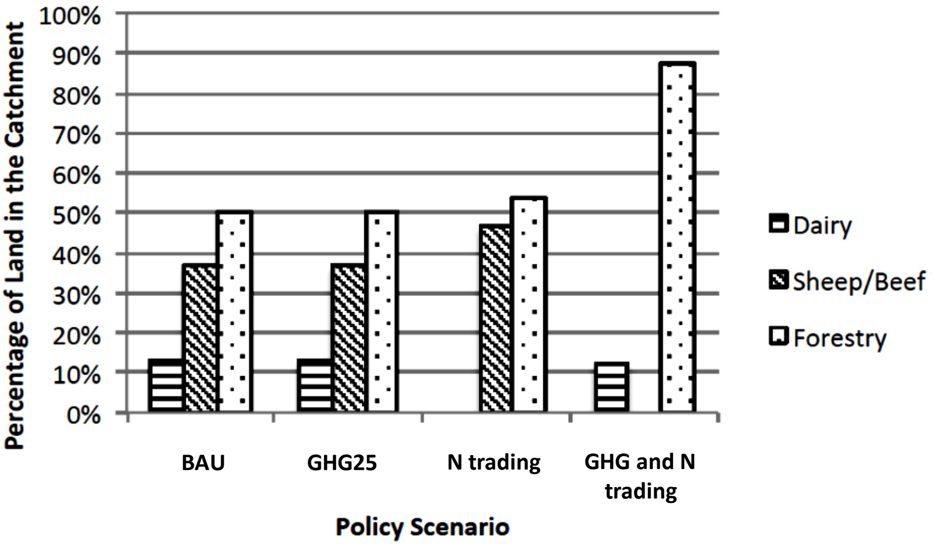


Figure 5: Land use under different scenarios, in % per year.

The land use change from the combined GHG price and N trading causes N leaching and GHG emissions to reduce by 74% and 155% respectively for the catchment (**Error! Reference source not found.**). Within individual land uses, reductions in N leaching and GHG emissions mirror the land use area results. Dairy farms see large reductions in GHG emissions and N leaching in the N trading scenario because of the large shits in area away from dairy and to less N intensive land uses (forestry and sheep and beef). Sheep and beef farms experience large decreases in GHG emissions and N leaching in the combined policy scenario because all sheep and beef land converts to less N intensive forestry.

Table 9: Relative change in GHG emissions and N leaching under individual GHG price and N trading scheme policies and under their combination

Environmental indicators	Baseline	GHG25	N trading	GHG25 and N trading
GHG emissions, t/yr	137,133	–49%	–125%	–155%
N leaching, kg/yr	506,299	–23%	–74%	–74%

In this assessment, Yeo et al. (2014) define production profit as agricultural commodity revenue less the costs of production, while profits refer to the production profit less the cost of N permits and GHG emissions (and net of any carbon sequestration payments).

Yeo et al. (2014) estimated the costs that dairy and sheep and beef farms incur with different policy settings (Table 10), finding that the joint policy affects the two groups differently. For dairy the profits (and production profits) are lower under both a GHG price and a N trading scheme. When the two policies are implemented together, the combined policy decreases profit compared to the stand-alone GHG scenario, but increases profit compared to the N trading scenario.

Profits (and production profits) for sheep and beef farms, like dairy farms, also decrease under a GHG price and a N trading scheme. Unlike dairy, production profits are lower when the policies are introduced in combination than compared to the stand-alone GHG price or the stand-alone N trading scheme. Profits in the combined policy scenario for sheep and beef, however, are greater than in the stand-alone N trading scheme but lower than the stand-alone GHG price scenario. This difference between profit and production profit for sheep and beef is because 100% of sheep and beef farmers switch to forestry in the combined policy scenario.

Care needs to be taken in Table 10 in the interpretation of abatement cost and compliance costs. Abatement cost is calculated as the difference between the production profit in the baseline and each policy scenario, while the compliance cost is calculated as the difference between profit in the baseline and profit in each policy scenario. These definitions may differ to other uses of the terms.

Table 10: Dairy and sheep and beef profits under individual GHG price and N trading scheme policies and under their combination, in $/ha/yr

Costs and profits	Baseline	GHG25	N trading	GHG25 and N trading
		Dairy		
Production profit	1,368	1,326	431	920
Profit	1,368	1,041	92	245
Abatement cost	n.a.	41	937	448
Compliance cost	n.a.	327	1,276	1,123
		Sheep and beef		
Production profit	480	437	354	71
Profit	480	422	152	246
Abatement cost	n.a.	42	125	409
Compliance cost	n.a.	57	328	234

Note: Production profit based on agricultural commodity revenue less the costs of production, while the profit is the production profit less the cost of N permits and GHG emissions (and net of any carbon sequestration payments). The compliance cost is calculated as the difference between profit in the baseline and profit in each policy scenario; abatement cost is difference between the production profit in the baseline and each policy scenario.

Looking at the distributional impacts of trading schemes, regardless of whether the N leaching permits are auctioned (i.e. regional councils sells N leaching permits to farmers) or freely allocated (i.e. optimal levels of allowed N leaching), it costs dairy farmers less when GHG emission prices are implemented together with the N trading scheme, since this decreases the N leaching permit price (Figure 6). In contrast, if the dairy farmers are granted baseline N leaching levels and the regional council buys back the N leaching permit levels (i.e. grandfathering), they benefit more than when the N trading scheme is implemented alongside the GHG prices. A similar trend in net revenues exists for sheep and beef, except that having optimal allowed levels of N leaching together with GHG prices have greater negative effects than the stand-alone policy of free allocation. The regional council benefits less when N leaching permits are auctioned and when there is both a GHG price and N leaching trading in place in comparison to stand-alone policies. This is because sheep and beef farmers shifted to forestry to receive carbon sequestration payment and the price of N leaching permits reduces.

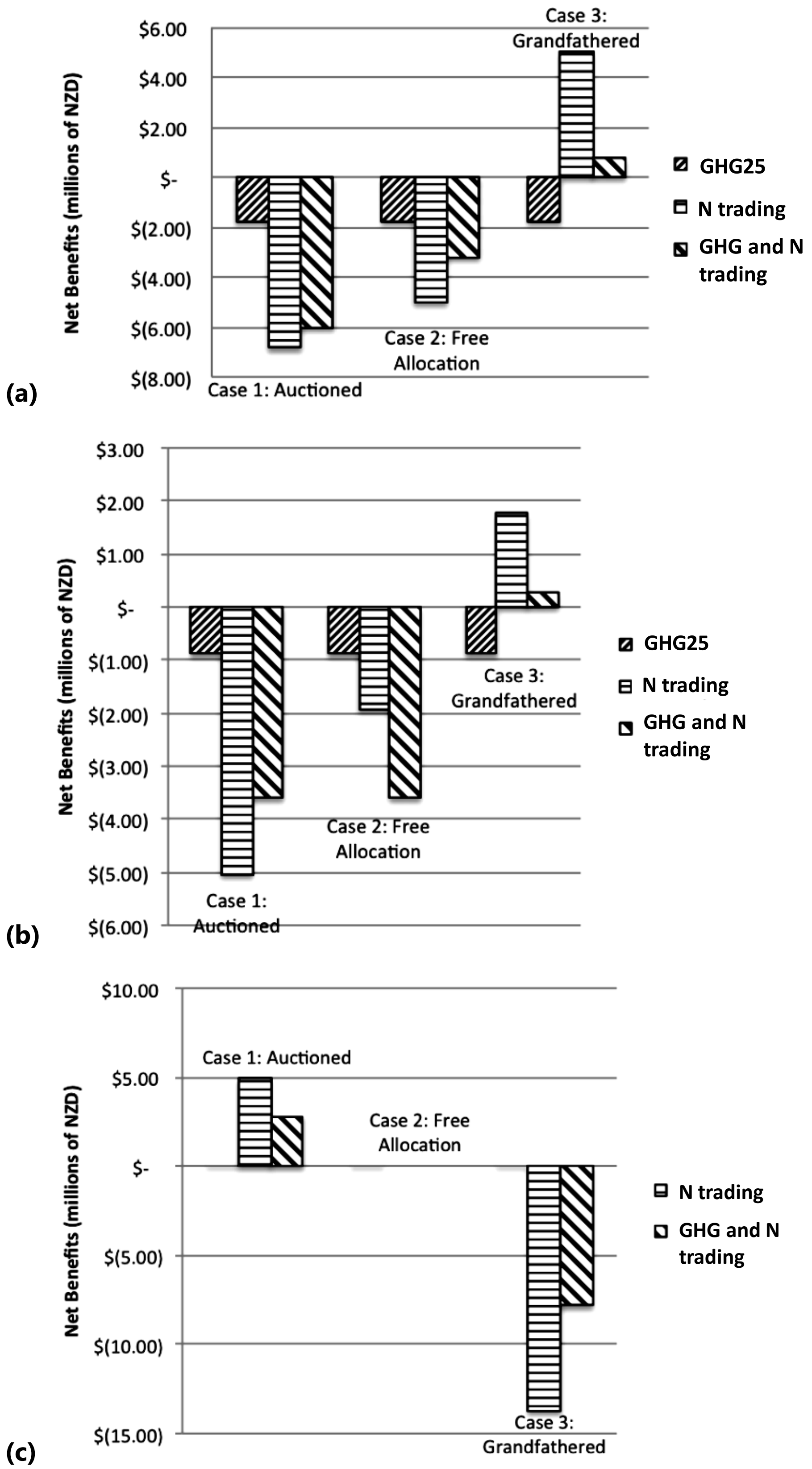


Figure 6: Net benefits to dairy (a), sheep and beef (b) and regional council (c) under different N leaching trading schemes (auctioned, free allocation and grandfathering) at GHG price, N leaching trading scheme and their combination scenarios, in million $/yr.

4) Publication by Daigneault et al. (2018)

This study used the NZFARM model to analyse the impacts of GHG and N leaching prices on land use allocation, net revenues, and agricultural and environmental outputs. The study is spatially explicit and considered all New Zealand territorial authorities and major land uses. The simulated GHG prices were \$10, \$20 and \$30/tCO_2e (GHG10, GHG20 and GHG30), and the N leaching prices were \$10, \$20 and \$30/kgN (N10, N20 and N30). These GHG and N leaching prices were analysed as stand-alone policies (i.e. \$20/tCO_2e and \$0/kgN; GHG20, N0) as well as in combination (i.e. \$20/tCO_2e and \$20/kgN). These prices are imposed as levies for all analysed land uses that emit GHG and leach N, and as payments for carbon sequestration in forestry. The results of the simulated GHG and N leaching prices were presented against the baseline situation, where the current situation is assumed with current land use area and no agro-environmental policy except payments given to forestry activities for carbon sequestration.

Caveats

The study relies on sample farm budgets estimated by Lincoln University's Financial Budget Manual, MPI's farm monitoring report, and other reports. These sources might not properly reflect the observed farm budgets. The study assumed there is no constraints in water availability for forestry across regions, and forestry substantially expands with joint policies.

Results

In both the stand-alone and combined scenarios, introducing GHG and N leaching prices reduces the area of sheep and beef most because of its high GHG emissions and N leaching levels as well as low net revenues (Table 11). The area of forestry increases the most, because of having carbon sequestration and thus the possibility to generate carbon revenues. Also, forestry has lower N leaching levels than other land uses. Because of high net revenues and low GHG emissions, the arable and horticulture areas increase. However, costs are substantial for arable and horticulture in scenario with the highest levels of N leaching prices and consequently the area of these land uses decrease.

Table 11: New Zealand-wide land use area in baseline and in GHG and N leaching prices scenarios

Scenarios	Dairy	Sheep/beef	Arable	Horticulture	Forestry	Other
Baseline, in 1,000 ha/yr	1,705	8,701	204	150	2,055	3,716
Percent change from baseline, in % per year						
GHG10, N0	–1	–3	1	1	11	1
GHG0, N10	–5	0	1	3	11	–3
GHG10, N10	–4	–7	3	4	21	6
GHG20, N0	–2	–5	3	2	21	0
GHG0, N20	–11	–25	0	1	16	53
GHG20, N20	–12	–37	2	1	42	69
GHG30, N0	–4	–7	5	4	31	0
GHG0, N30	–16	–47	–7	0	19	106
GHG30, N30	–22	–63	–14	–7	53	130

In Table 12, results are given on net revenues and environmental outputs. The results show that jointly implementing GHG and N leaching prices lead to larger decrease in net GHG emissions, nutrient losses and soil erosion than stand-alone policies, while having only a marginal economic burden on landowners. The increase in the stand-alone N leaching price has larger economic and environmental reduction effects than do GHG prices. For example, net revenues decrease by 5% with the stand-alone N leaching price of \$20/kgN, but decreases by 1% with a stand-alone GHG price of \$20/tCO$_2$e. In the scenario that combines both a GHG price and a N leaching price (\$20/tCO$_2$e and \$20/kgN), the summed net revenues from all land uses reduce by 6%. The slightly lower net revenues from the combined policy scenario than from the stand-alone N leaching price scenario is due to generating carbon sequestration revenues from the increased forestry area. The impacts are larger with larger GHG and N leaching prices.

Substantial net GHG emissions, nutrient leaching and soil erosion reduction can be achieved at the highest combined GHG and N leaching prices scenario. However, the water yield further reduces with the increase of GHG and N leaching prices.

Table 12: New Zealand-wide key outputs in baseline, GHG price and N leaching price scenarios, in per year

Scenarios	Net revenue ($Bn)	GHG (Mt)	Carbon seq. (Mt)	Net GHG (Mt)	N leach (1,000t)	P loss (1,000t)	Soil erosion (Mt)	Water yield (mm)
Baseline	11.3	34.6	24.3	10.3	216	11.8	294	869
Percent change from baseline								
GHG10, N0	–1	–2	8	–26	–1	–2	–1	0
GHG0, N10	0	–1	7	–16	–3	–1	–1	0
GHG10, N10	–1	–4	15	–50	–4	–5	–2	0
GHG20, N0	–1	–4	15	–50	–2	–4	–1	0
GHG0, N20	–5	–7	12	–50	–17	–20	–3	–6
GHG20, N20	–6	–18	31	–134	–20	–29	–5	–5
GHG30, N0	–2	–6	23	–75	–3	–6	–2	–1
GHG0, N30	–11	–19	15	–102	–30	–38	–12	–10
GHG30, N30	–13	–36	40	–215	–37	–52	–14	–12

Figure 7 shows the net revenues by territorial authority for the stand-alone GHG ($20/t$CO_2$e; referred as GHG20, N0) and N leaching ($20/kgN; referred as GHG0, N20) prices, and the combination ($20/t$CO_2$e and $20/kgN; referred as GHG20, N20). Most territorial authorities have minor decrease in net revenues, except for the substantial net revenue decrease for the territorial authorities located on the east coast of South Island.

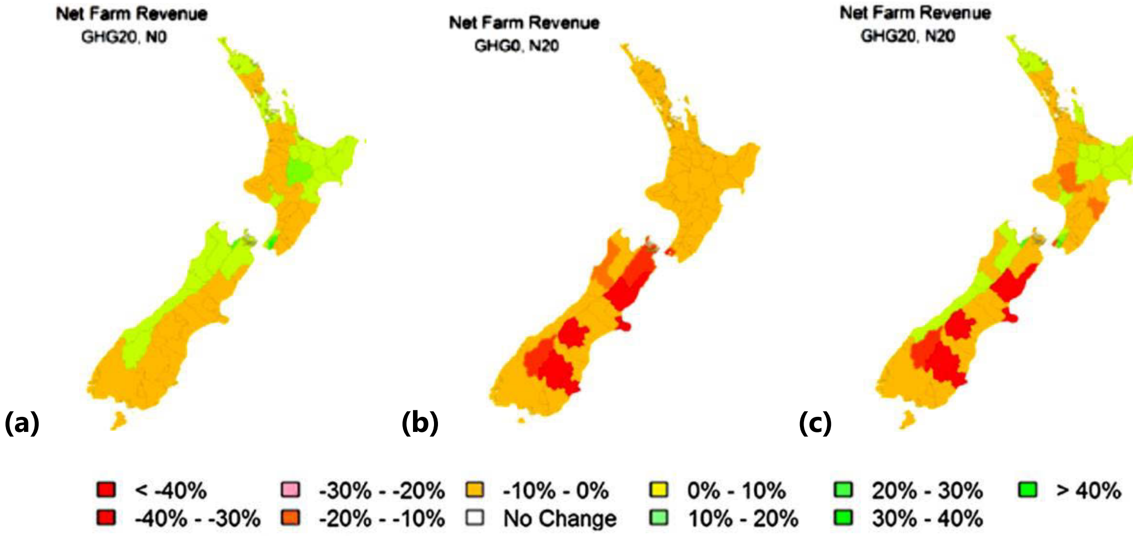


Figure 7: Relative change from the baseline of total net revenues for GHG price $20/tCO2e (a), N leaching price $20/kgN (b) and their combination (c) scenarios, in per year.

Figure 8 gives the change in net GHG emissions (the difference between GHG emissions and carbon sequestration) relative to baseline scenario. The combination of GHG and N leaching prices ($20/tCO$_2$e and $20/kgN) reduces net GHG emissions and the reduction is substantial across almost all of New Zealand.

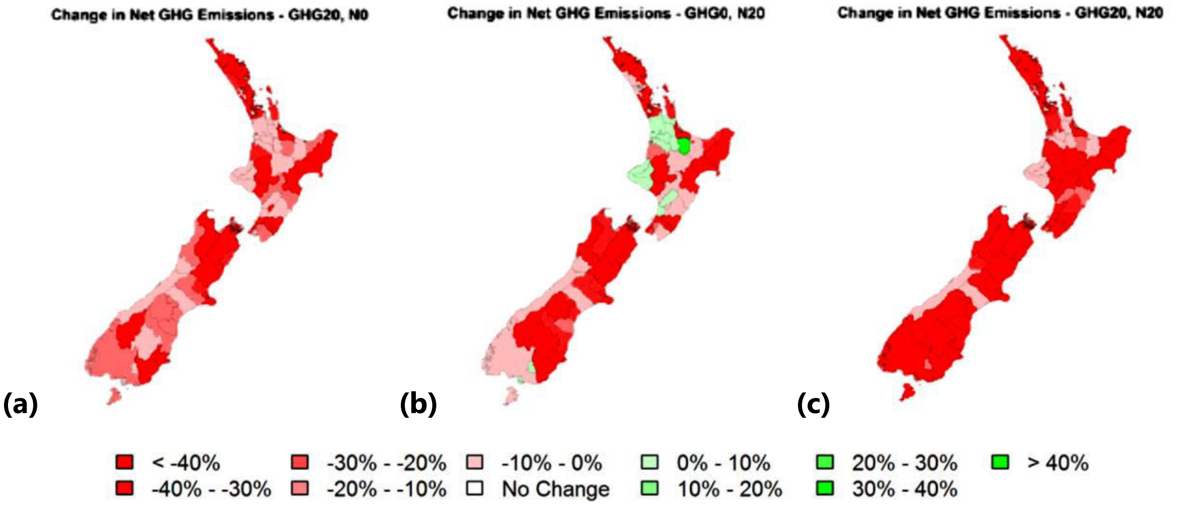


Figure 8: Relative change from the baseline of net GHG emissions for GHG price $20/tCO2e (a), N leaching price $20/kgN (b) and their combination (c) scenarios, in per year.

Figure 9 gives the change in N leaching relative to baseline scenario.

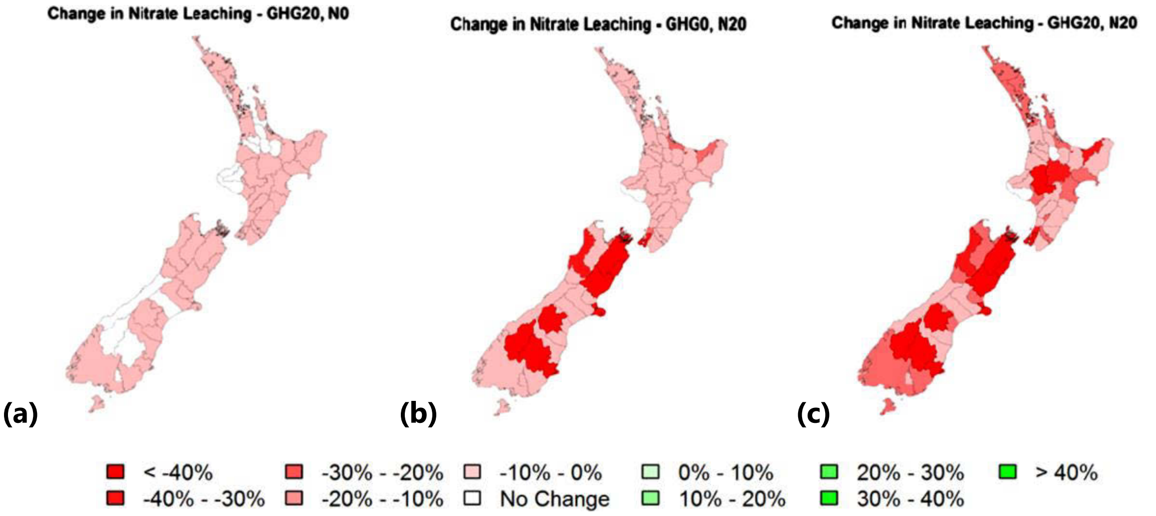


Figure 9: Relative change from the baseline in N leaching for GHG price $20/tCO$_2$e (a), N leaching price $20/kgN (b) and their combination (c) scenarios, in per year

5) Publication by Ausseil et al. (2019)

This study combined global assumptions from the IPCC scenario framework, GHG price projections, and 20% reduction in N and P leaching and sediment load to assess future scenarios. It used a spatially explicit integrated assessment that combined economic and biophysical models to help quantify the potential effects of a complex set of climate-induced impacts, coupled with regional environmental and land use policy. Three IPCC scenarios involving stakeholders were chosen to gain insight into local sensitivity to climate versus socio-economic change. Under three IPCC scenarios, GHG prices were projected to \$0, \$288 and \$611/tCO_2e in 2065 and to \$0, \$1,243 and \$2,641/tCO_2e in 2100. Also, 20% catchment-level N and P leaching and sediment load reduction were assumed. The study area is the Kaituna catchment, in the Bay of Plenty. The results provide the direction of changes for demographic, economic, and environmental factors, including some ecosystem services.

The study does not explicitly provide results under nutrient leaching and sediment reduction target. Instead, the study focuses on the effects of projected climate change adaptation and mitigation scenarios. Table 13 provides climate change adaptation and mitigation scenarios. Shared policy assumptions allow national-level development choices that may reinforce global trends or actively go against them. They contain a mix of climate-specific policies and non-climate-specific policies that have indirect but significant climate impacts, or influence climate-related vulnerability or adaptation options. The more detailed description of scenarios can be found in Ausseil et al. (2019).

Table 13: Narratives for three climate change projection scenarios

Projection scenario	Representative concentration pathways (RCP)	Shared socio-economic pathways (SSP)	Shared policy assumptions (SPA)
Unspecific Pacific (8.5/3/A)	Very high emissions (8.5 W/m2)	3 Fragmented world	A: With NZ lagging relative to global efforts to mitigate, nationally there is only incremental and reactive adaptation on a piecemeal basis.
Kicking, screaming (4.5/3/A)	Intermediate stabilization (4.5 W/m2)	3 Fragmented world	A: With NZ lagging relative to global efforts to mitigate, nationally there is only incremental and reactive adaptation on a piecemeal basis.
Clean Leader (4.5/5/F)	Intermediate stabilization (4.5 W/m2)	5 Conventional development (fossil powered growth)	F: NZ ahead of increasingly stringent global efforts to mitigate, and strategic approach to adaptation to not just maximize economic opportunities but also to achieve sustainability across three pillars.

Caveats

The study used many assumptions and policies, which makes it difficult to understand the impacts of specific policies. The study implicitly considers and presents the policies on GHG prices and 20% reduction in N and P leaching and sediment. The study also relies on farm budgets estimated by Lincoln University's Financial Budget Manual, MPI's farm monitoring reports, and other reports. These sources might not properly reflect the observed farm budgets.

Results

Figure 10 provides results on land use change. Looking towards 2065, in both scenarios involving Representative concentration pathways (RCP) 4.5, the greatest change in land use is estimated to be a shift from sheep and beef and dairy to forestry. This is because although there is an estimated increase in milk and meat prices compared to 2015, the carbon price increase is larger, leading to a projected increase in forestry profits and area. In scenario RCP 8.5/SSP3, the absence of a carbon price and the large projected meat prices lead sheep and beef to be relatively more profitable. Hence, there is a large shift in land use area from forestry and scrub back to sheep and beef.

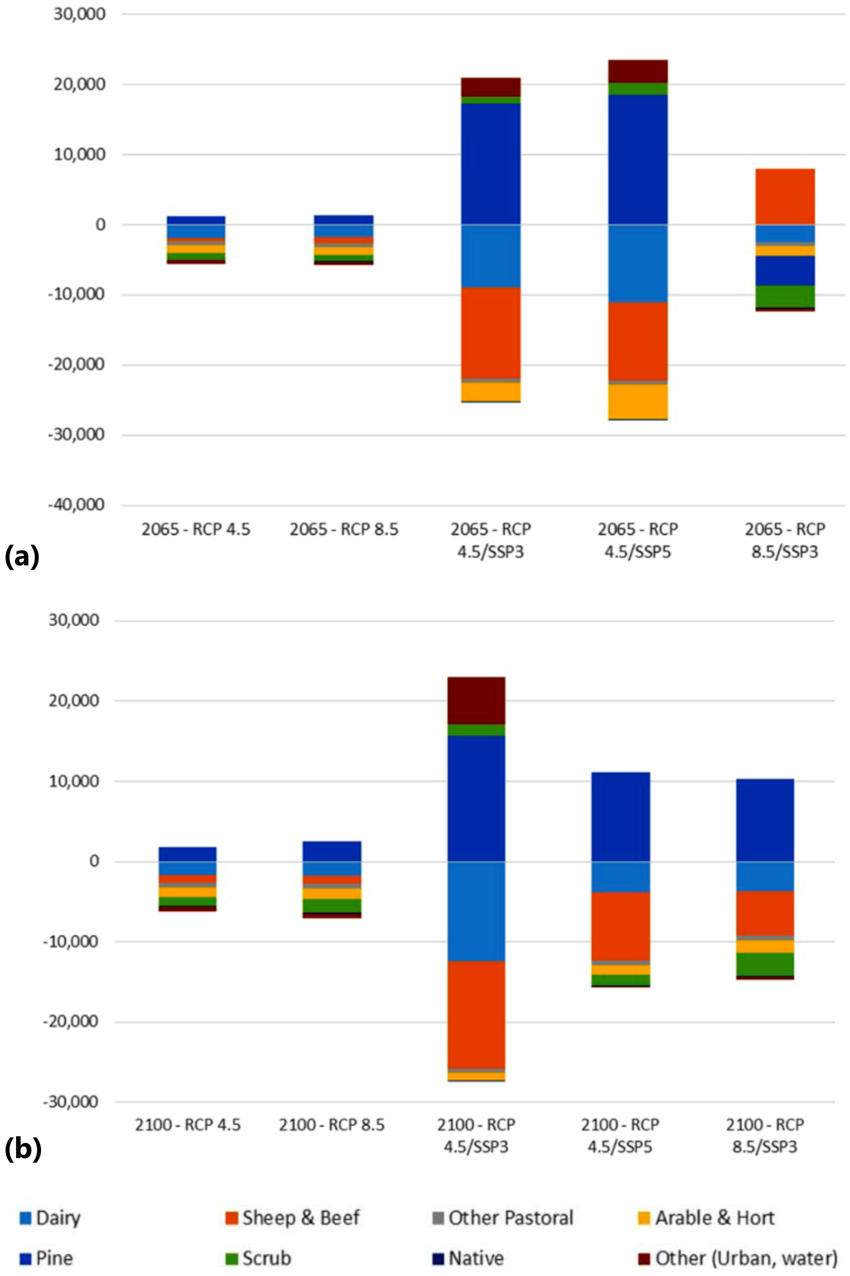


Figure 10: Land use change from the baseline under different scenarios in 2065 (a) and 2100 (b), in ha/yr.

Net revenues change similarly to the land use area pattern (Figure 11). The substantial increase in carbon prices increases net revenues from exotic forestry (pine) and native trees, due to their carbon sequestration potential and increase in area. In RCP8.5/SSP3, the absence of a carbon price and the large projected prices lead sheep and beef to be highly profitable, and thus there is net revenue increase from sheep and beef. In other scenarios net revenues changed slightly.

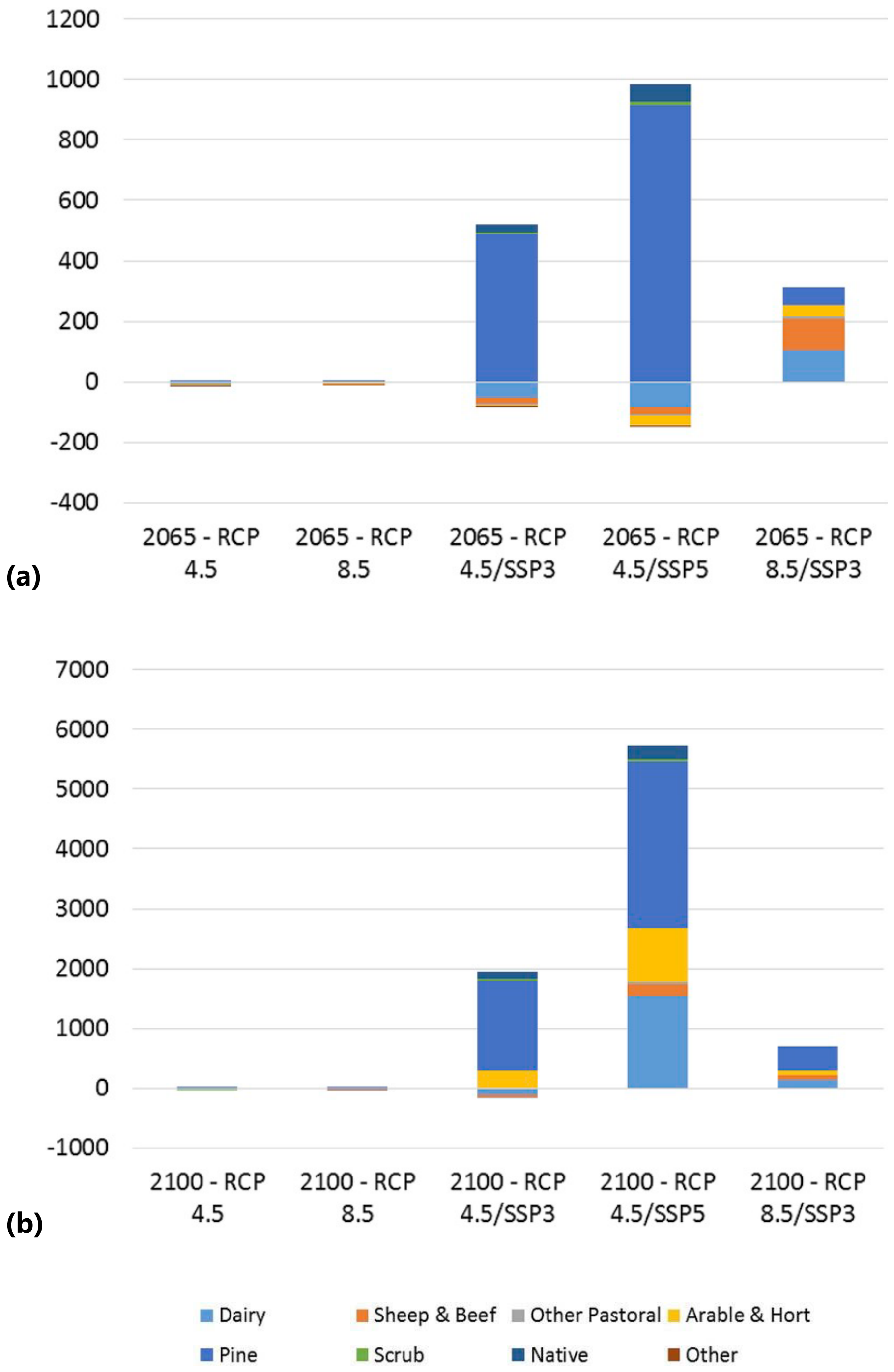


Figure 11: Net revenue change from the baseline under different scenarios in 2065 (a) and 2100 (b), in million $/yr.

Environmental outputs are equally impacted in both RCP 4.5/3/A and RCP 4.5/5/F scenarios in 2065 (Figure 12). Climate regulation in the form of reduced net GHG emission improves as carbon sequestration increases and GHG emissions decrease because of the decrease in livestock numbers. Pressure on water quality is also decreasing with the decrease in pastoral area and animal excreta. Erosion decreases with a decrease in soil loss, due to the increase in tree cover, especially on erosion-prone areas (e.g. in hill country of the catchment). In contrast, water yield is slightly decreasing as the increase in forestry area reduces water yield (see water regulation bar in **Error! Reference source not found.**). The scenario RCP 8.5/3/A contrasts with the two others: climate regulation is worse, with a net increase in GHG emissions. Water quality could also be affected with more P loss, although N leaching is projected to be at a similar level to 2015.

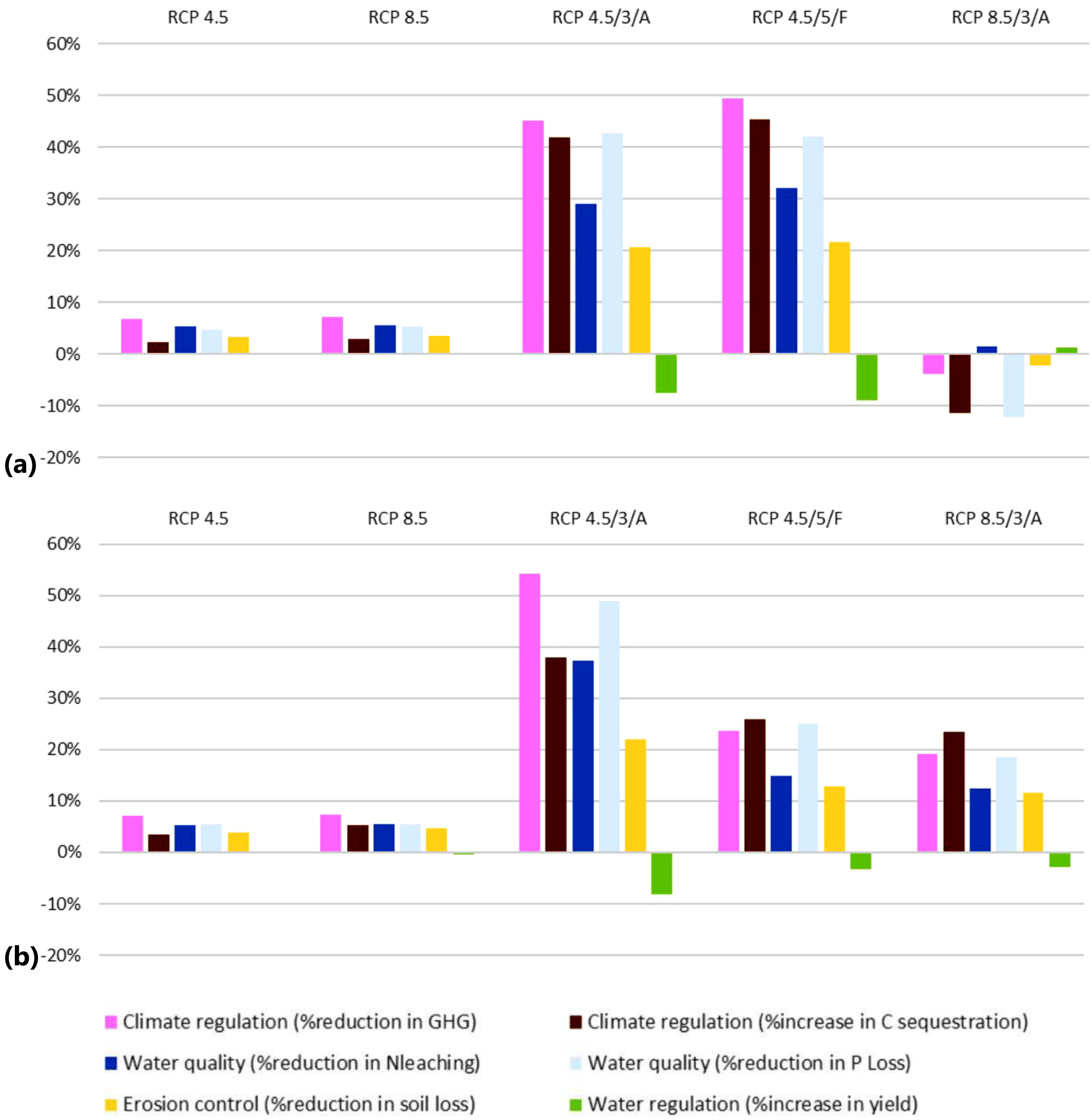


Figure 12: Environmental output change from the baseline under different scenarios in 2065 (a) and 2100 (b), in % per year.

6) Publication by Djanibekov et al. (2019)

This study analysed the impact of different projected agro-environmental policy scenarios to 2035 and 2050 on land use allocation, net revenues, and agricultural and environmental outputs, using the NZFARM model. All New Zealand regions and major land uses were considered. In the combination scenario that includes both climate and freshwater policies, the simulated GHG prices were $40/tCO$_2$e in 2035 and $50/tCO$_2$e in 2050, and 5-m riparian buffers on each side of livestock areas were studied. These policies were analysed as stand-alone policies and in combination. In the stand-alone policies, prices for GHG emissions and carbon sequestration were analysed separately. In the combination scenario, the 1 Billion Tree Programme (0.4 million ha afforested (1/3 with *Pinus radiata* and 2/3 with indigenous species)) and the National Environmental Standard for Plantation Forestry (5-m riparian buffer taken out from production on all land with exotic forest) were also included. As a stand-alone policy, the GHG prices were $27, $40 and $74/tCO2e in 2035 and $35, $50 and $96/tCO2e in 2050. In addition, the authors use a 95% free allocation to price agricultural biological GHG emissions (only CH4 and N20), meaning farmers only face a direct price on 5% of their biological GHG emissions. Riparian buffer widths in the stand-alone policy were 5-m and 30-m on all land in livestock production. The study relied on industry data and included different dairy and sheep and beef systems across regions. The study used outputs from the Lincoln Trade and Environment Model on relative projected land use net revenues till 2050.

The results were presented against the baseline situation, where the current situation is assumed with current land use area and no agro-environmental policy. The study does not provide physical results on nutrient leaching outputs or other freshwater related outputs.

Caveats

The study considered only GHG emissions and carbon sequestration as environmental outputs and did not include any information related to freshwater indicators. Also, the study did not include the water yield, a reduction of which can inhibit the expansion of forestry area. The study relies on land use information from secondary data from 2012, while economic and environmental outputs are from industry from 2017.

Results

The area in pastoral land uses decreases due to the pricing of agricultural GHG emissions and carbon sequestration in forestry, as well as the establishment of riparian buffers under the freshwater policy (**Error! Reference source not found.**). Deer has the largest decrease in area in relative terms. The decrease in deer and other pasture area is slightly larger in 2050 than in 2035 because these land uses have lower projected profits than other land uses. The area in sheep and beef reduces by about 7% (i.e. 0.5 million ha) in both 2035 and 2050, which is the largest decrease in area in absolute terms among land uses. The largest increase in area is for forestry to meet the proposed objectives of the One Billion Tree programme. The area in arable and horticultural crops increases, and this increase is slightly larger in 2050 than in 2035 primarily because of higher projected profits from these land uses.

The stand-alone agricultural GHG emission price scenario has an unsubstantial effect on land use allocation due to 95% free allocation, where farmers face a direct price only on 5% of their biological GHG emissions. Only payments for carbon sequestration has a larger impact on land use change. In only the freshwater policy a 5-m riparian buffer establishment is set on livestock farms adjacent to rivers. This buffer area is taken out from production, and in turn dairy has the largest decrease in area.

Table 14: Relative change from the baseline of land use area under the combined, agricultural GHG emission price, carbon sequestration price, and freshwater policy scenario, in % per year

Land use	Combined		Agricultural GHG emission price		Carbon sequestration price		Freshwater policy	
	2035	2050	2035	2050	2035	2050	2035	2050
Arable	4	4	0.2	0.3	0.0008	0.02	0	0
Fruits	2	2	0.3	0.5	3	2	0	0
Vegetables	3	3	0.5	0.8	3	3	0	0
Pipfruit	1	1	0.1	0.5	2	0.8	0	0
Viticulture	6	6	0.8	1.0	4	4	0	0
Forestry	6	6	0.6	2.2	19	20	0	0
Dairy	–2	–2	–0.1	–0.2	–0.8	–0.7	–2.6	–2.6
Sheep/beef	–7	–7	–0.1	–0.5	–5	–5	–1.6	–1.6
Deer	–12	–12	–1.4	–1.8	–10	–14	–0.8	–0.8
Other pasture	–6	–6	–1.5	–1.9	–3	–4	–0.6	–0.6
New indigenous forest	3	3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Note: New indigenous forests are considered in the One Billion Tree programme, which is included in the combined scenario; we present results here as stand-alone and combined GHG prices (for both emissions and sequestration) of \$40/tCO2e and \$50/tCO2e in 2035 and 2050 respectively, and 5-m riparian buffer.

Table 15 shows that the combination of policies is the most cost-effective way to reduce GHG emissions. 5-m riparian buffer substantially reduces net GHG emissions and net revenues.

Table 15: Relative change from the baseline of net revenues and net GHG emissions, in % per year

Scenarios	**Net revenue (% change)**						**Net GHG emissions (% change)**					
	2035			**2050**			**2035**			**2050**		
Climate policy												
GHG price	$\$27/\text{tCO}_2\text{e}$	$\$40/\text{tCO}_2\text{e}$	$\$74/\text{tCO}_2\text{e}$	$\$35/\text{tCO}_2\text{e}$	$\$50/\text{tCO}_2\text{e}$	$\$96/\text{tCO}_2\text{e}$	$\$27/\text{tCO}_2\text{e}$	$\$40/\text{tCO}_2\text{e}$	$\$74/\text{tCO}_2\text{e}$	$\$35/\text{tCO}_2\text{e}$	$\$50/\text{tCO}_2\text{e}$	$\$96/\text{tCO}_2\text{e}$
GHG emission price with 95% free allocation	–0.5	–0.7	–1	–0.5	–0.7	–2	–2	–2	–7	–2	–5	–9
Carbon sequestration rewards for forestry	7	10	20	7	10	23	–17	–38	–73	–17	–38	–74
Water policy												
Riparian buffer widths	5m		30m	5m		30m	5m		30m	5m		30m
Freshwater policy	–23		–34	–20		–31	–6		–38	–6		–38
Combined climate and water policy												
Combined scenario	–22			–13			–29			–27		

7) Publication by Neverman et al. (2019)

This study analysed the impact of sediment reduction measures while considering a carbon price of $25/tCO$_2$e on the adoption of mitigation practices, net revenues and environmental outputs. The study used two types of economic models: NZFARM and the valuation of ecosystem services. First, the authors used the NZFARM model to simulate the impacts of sediment reduction targets and the consequent adoption of sediment mitigation practices on farms in each catchment. The NZFARM model estimated costs from introducing sediment mitigation measures on the available mitigatable area. The model simulated baseline and sediment reduction target scenarios. The baseline included the present pattern of the farms' areas and sediment generation in catchments and did not consider any environmental policies. The sediment reduction target scenario included the target level of sediment reduction for each catchment and sediment reduction mitigations such as afforestation and whole-farm planning. In this scenario, carbon sequestered by afforestation generated revenues of $25/tCO$_2$e. The model did not explicitly present other land uses and only considered eroded land areas suitable for mitigations. Thus, the study did not classify these land areas by land uses (i.e. whether it is dairy or sheep and beef). Based on observation, most of these sediment mitigatable land areas are under pastoral farms. The NZFARM model is simulated for a single year.

There are also non-monetised benefits and impacts on wider society via the change in environmental outputs from introducing sediment reduction measures. Using the results of the NZFARM model, the authors monetised the value of environmental services from sediment reduction measures such as water clarity and carbon benefits and avoided costs of sediment and dredging over 50 years using 4% and 6% discount rates. In this analysis, carbon benefits included the benefits from GHG emission reduction and carbon sequestration increase. The study used a benefit transfer approach to assign monetary values to non-marketed environmental products.

Both NZFARM and the valuation of ecosystem services approaches relied on erosion data from NZeem® model.

Caveats

The study area is limited to the sediment mitigatable area identified in this study. Therefore, the combined policy might not be relevant in other land use areas. Also, the study did not include the water yield, which can reduce the expansion of forestry area. Moreover, the study did not explicitly analyse different land uses, which makes it difficult to understand the policy impacts on different land uses.

Results

To meet the sediment reduction targets (sedimentation reduction target scenario), afforestation is needed on about 1.056 million ha and whole-farm planning on 6,055 ha. After meeting the catchment sedimentation reduction targets, about 1.2 million ha do not need any mitigations and remained in the current land use (Table 16).

Table 16: Mitigatable land area allocated for no mitigation, whole-farm planning and afforestation in baseline and sedimentation reduction target scenarios, in 1,000 ha/yr

	Baseline	Sedimentation reduction target scenario		
		Area that does not require further mitigation	Whole-farm planning	Afforestation
Land area	2,268	1,207	6.1	1,055

By implementing sediment reduction targets, afforestation, and whole-farm planning on mitigatable land, about 4 million tonnes (13%) of sediment load can be reduced (Table 17). GHG emissions reduce by 34.5% from the baseline, while carbon sequestration increases by 19.8 million tCO_2. N and P leaching reduce by 1.3% and 5.1% respectively.

Table 17: Net revenues, sediment load GHG emissions, CO_2 sequestration, N leaching and phosphorous loss outputs in baseline and sedimentation reduction target scenarios, in per year

Scenarios	Net revenues ($1m)	Sediment load (1,000 t)	GHG emissions (1,000 tCO_2e)	Carbon sequestration (1,000 tCO_2e)	N leaching (t)	P loss (t)
Baseline	803	29,579	6,703	0	26,811	1,264
Sedimentation reduction target scenario and \$25/tCO_2e	981	25,668	4,393	19,765	26,473	1,199

There are also non-monetised benefits and impacts on wider society via the change in environmental outputs from introducing sediment reduction measures. Results of this study show that the net present value of sediment reduction benefits over 50 years with 4% discount rate range between $75 and $226 million, depending on the assumed value of the marginal avoided cost of sedimentation (Table 18). Under a 6% discount rate, the 50-year net present value of sediment benefits are between $51 and $154 million depending on the assumed value of the avoided cost of sedimentation. The discounted net revenues of water clarity benefits over 50 years for 4% and 6% discount rates are $334 and $504 million respectively. The dredging benefits range from $19 million to $31 million. The 50-year NPV of carbon benefits varies between $5 billion at a 5% social carbon cost rate and $31 billion at a 2.5% social carbon cost rate.

Table 18: Monetised benefits and costs of environmental services from sediment reduction measures, discounted costs and benefits over 50 years in $ million

Description of costs and benefits	4% discount rate	6% discount rate
Cost		
Lost profit, increased costs	7,098	5,292
Benefits		
Avoided cost of dredging	27–31	19–22
Avoided cost of sediment	75–226	51–154
Carbon benefits	8,000–31,000	5,000–21,000
Water clarity benefits	504	334
Net returns (benefits – costs)	1,508–31,761	112–16,218

3.3 Climate policy

Our literature review found two studies that assessed the impact of climate policy on freshwater indicators (see Table 4) – Daigneault et al. (2011) and Morgan & Daigneault (2015). The Daigneault et al. (2011) study also assessed the impact of freshwater policy on climate indicators and is included in sections on individual climate policy and freshwater policy. Daigneault et al. (2011) and Morgan & Daigneault (2015) used simulation models to investigate the impacts of different GHG price levels in the Hurunui-Waiau catchment on land use change, net revenues and climate and freshwater indicators. Daigneault et al. (2011) used NZFARM land use optimisation model, while Morgan and Daigneault (2015) used an agent-based model linking a farmer behaviour model to NZFARM. Specific details of the studies and their results can be found in Table 20 in Appendix 2.

The two climate policy studies, despite different modelling frameworks, showed similar trends. As GHG prices increased, net GHG emissions and N and P losses all decreased.

Morgan & Daigneault (2015), in 10-year time step, estimated the impact of GHG prices ($20, $40 and $60/tCO$_2$e) on land use, net revenue, GHG emissions, carbon sequestration, N leaching and P losses till 2060. Daigneault et al. (2011), in a single time period, assessed the impacts of GHG prices ($20 and $40/tCO$_2$e) on land use, net revenue and the same indicators as Morgan & Daigneault (2015).

Care should be taken when comparing the results from these two studies as there are differences in assumptions that need to be noted. In particular, Morgan & Daigneault (2015) included a 2% year on year increase in commodity prices as their study was dynamic and assessed the impacts of GHG prices over a projected 50-year time horizon. Therefore, over the 50 years projection net revenue, GHG emissions and nutrient losses all increased. However, to determine the impact of pricing GHG emissions the change in net revenue, GHG emissions and nutrient losses should be compared at the same point in time.

The differences in the modelling results comes from the induced land-use change as a result of the climate policy. Daigneault et al. (2011) showed that under the GHG price of $40/tCO$_2$e, land use moved from scrub (-3%) and pasture (-6%) to cropland (82%), forest (49%), and horticulture (32%).

Morgan & Daigneault (2015), however, found in their study that there was a modest increase in dairy area at the expense of sheep and beef and forestry at $20 and $40/tCO$_2$e. This was driven primarily because the net revenues derived from dairy, even with a GHG price, are still higher than for sheep and beef and forestry. It was not until the GHG price reached $60/tCO$_2$e that dairy area moved into forestry. The 2% increase in commodity prices in this study meant that GHG prices had to be quite high before the net revenue from dairy commodity income less cost of GHG emissions) was no longer higher than forestry revenues. At this point, land area moved out of dairy into forestry and sheep and beef.

3.4 Freshwater policy

Our literature review found 7 studies that explicitly analysed freshwater policy, while also incorporating GHG emissions as an output (see Table 5). Of these studies, 5 model limits on nutrients (Daigneault et al. 2011; 2013; 2017b; Samarasinghe et al. 2011; Strutt & Rae (2011)), Duhon et al. (2015) analyses the progress of the Lake Taupo nitrogen trading scheme, and another study analyses the implementation of management options to meet the freshwater standards (MfE 2019). Studies differ in their scale and geographical area of analysis, except Daigneault et al. (2011) and Samarasinghe et al. (2011), where both studies considered the Hurunui catchment. Compared to the studies that jointly analyse climate and freshwater policy, these studies do not price GHG emissions. Instead, they tracked any change in GHG emissions and/or carbon sequestration as a result of the freshwater policy. Specific details of the studies can be found in Table 21 in Appendix 3.

Both Daigneault et al. (2013) and Duhon et al. (2015) research the cap and trade schemes to reduce N leaching. Daigneault et al. (2013) looks specifically at one catchment simulating four different policy scenarios to protect 90% of aquatic species, which equates to 45% decrease in N leaching. Of the four policy scenarios, “farm-specific caps”, “cap and trade” and “hybrid policies” all successfully reach the target, while “improved land management practices” (39% decrease in N leaching) does not meet the target because it is the only scenario that does not cap N leaching at 45%. It, instead, assumes land management practices will achieve N leaching targets. As opposed to strict caps, land management practices do not guarantee that a N reduction target is achieved, only that the practice is implemented. The effectiveness of practices vary spatially and with farmer skill levels. In addition, farmers might adopt practices that improve freshwater but continue to intensify production (e.g. changing stocking rates or switching to a more intensive land use). Therefore, the findings from economic models may overestimate the reductions in freshwater indicators or GHG emissions from policies based on land management requirements. A cap, on the other hand, puts the onus on the farmer to implement the practice or practices needed for their specific farm to reach the pollutant cap.

GHG emissions in both studies drop in each of the four scenarios as well as revenue. The authors note that potentially significant flow on effects, such as regional employment and regional GDP, are not included in the model and need to be considered. While Daigneault et al. (2013) simulate proposed policy, Duhon et al. (2015) analyse the effectiveness of the already implemented Lake Taupo nitrogen capping scheme. The results show that the programme is working to reduce N leaching through limiting intensification and that the trading mechanism is working to reduce costs. The authors also found evidence that farmers were entering the ETS market. The farmers in the area still face significant economic and social costs.

As opposed to implementing nutrient cap and trading schemes, Daigneault et al. (2017a) model the effectiveness of different bundles of mitigations at achieving the freshwater targets of the New Zealand regional councils. Key takeaways from the results are that many of the targets for N, P, and *E. coli* were reduced past the target because mitigations taken to meet one of the targets often improved the others. Intense dairy regions require the highest reduction in N and P. Meeting the targets reduced agricultural GHG emissions by 2.4%, but increasing the targets only had marginal further reductions on emissions. Emissions are reduced through a combination of de-stocking and afforestation, meaning the N targets most strongly drove the reduction in GHG. Samarasinghe et al. (2011) imposed 15% and 30% limits on N and P loss in the Hurunui catchment. They compared data from two biophysical models, OVERSEER and SPASMO. They found that the N targets could be met with limited losses in net revenue (0.5% loss for the 15% target and 6% loss for the 30% target) due to a conversion from pastoral land uses to horticulture, arable and forestry.

The Daigneault et al. (2011) study models how a catchment that is increasing irrigation would react if a nutrient cap were to be implemented. This study also assessed the stand-alone climate change policy (see Climate policy section). The authors limit N and P at the baseline levels and allow for trading within the catchment. They found that both revenue increases, net GHG emissions reduce, and N and P levels stay constant. The results show that a shift to forestry, horticulture, and cropland would earn carbon credits and offset N and P leaching.

A recent report by MfE (2019), analysed the impacts of streamside planting (to reduce rural runoff), retention of more natural wetlands, and potentially less intensive stocking to meet the freshwater policy on GHG emissions. The study projected the analysis till 2035 and showed that the mitigation options implemented for freshwater policy also reduce GHG emissions and in 2020 the GHG levels would reduce by 9 $ktCO_2$, while in 2035 the reduction could be 786 $ktCO_2$.

Strutt & Rae (2011) analysed the impact of N leaching reduction targets on changes in management practices and consequent economic and environmental outputs of dairy farms in New Zealand. This is the only study we have identified that focuses its analysis on agricultural trade impacts of policies. The results of the study show that to meet the N leaching targets, dairy farms need to reduce fertiliser use and stocking rates. The value added in dairy farming can fall between 2% and 13% depending on N leaching target levels. Export earnings from dairy commodities may reduce between US$269 million (NZ$386 million as of 2010) and US$1,145 million (NZ$1,644 million as of 2010).

3.5 Land management practice change

The literature review included research focusing on land management practice change that affects freshwater and climate indicators. We define land management practices as individual changes made on-farm that, when implemented individually or bundled together, impact freshwater or climate outputs. In total, 22 studies focused on land management practices were found (see Table 6). These studies include the practice analysed, the scale, and the land use/landcover. The literature is grouped by practice type. A more detailed summary of each study with specific results can be found in Table 22 in Appendix 4. When comparing work on similar practices it is important to note that although the practices are similar, the setting, scale or details of the practices can be different.

In total, 6 studies that focus on afforestation are included in the literature review, as well as 2 studies that include tree planting in mitigation bundles. In each study, afforestation improved water quality and sequestered carbon. Dymond et al. (2012) models the effect of planting *Pinus radiata* across different areas of New Zealand. Their results show significant monetary benefits throughout much of the country due to decreases in erosion and income through carbon credits. Ausseil et al. (2013) model hill country erosion in the Manawatu catchment; a highly eroded area. They found that afforestation leads to significant increases in climate regulation and erosion control as well as slight increases in water quality and wood provision. Dymond et al. (2013) simulated natural regeneration of grass and shrubland as opposed to planted forestry and found over 2 million ha of pastureland in New Zealand that could be converted to indigenous forestry. The positive benefit/cost ratio in the model is partly driven by a high monetary value on biodiversity.

Walsh et al. (2017) estimated benefits and costs of afforestation expansion on erosion-prone pastoral hill country in the Manawatu catchment. They include three scenarios: exotic pine, indigenous forest with no production activities and indigenous forest with honey production. They showed that afforestation can provide substantial economic, carbon, and water quality benefits, with all scenarios having positive net present values. The exotic pine scenario had the greatest benefit due to high carbon credit values and profit from forestry, while the indigenous forest without production scenario had the lowest net present value because of a lack of production and lower carbon credits for indigenous forests. Walsh et al. (2019) also estimated whether it is more financially and environmentally viable to shift from exotic to indigenous forestry. Based on estimated benefits and costs, they showed that the net present value of indigenous forestry is negative due to its high costs. However, the authors argued that various potential environmental benefits, such as reduction in erosion and GHG emissions, improvement in water quality, and an increase in carbon sequestration and biodiversity, can be achieved.

These practices can, however, have further knock-on effects, both positive and negative. Three of the afforestation specific studies (Ausseil et al. 2013; Dymond et al. 2012, 2013) use an ecosystem services approach, including more ecosystem services than just freshwater or carbon related ecosystem services. Dymond et al. (2012) pointed out that large-scale afforestation can impact a catchment's water yield, which is important in catchments with high demand for irrigation. In these catchments, the erosion and carbon sequestration benefits can be outweighed by the loss in irrigation capability. Ausseil et al. (2013) found a decrease in water yield in their study in the Manawatu catchment. Wilcock et al. (2008) analysed a range of practices including afforestation and riparian buffers finding that both practices reduce loss of N, P, sediment and *faecal coliformi*.

Daigneault et al. (2017b) simulated creating a planted riparian buffer on farm waterways throughout the country. Like the studies on afforestation, they found significant reduction in net GHG emissions, N leaching and P loss. Additionally, they saw a 23% increase in biodiversity leading to a total benefit/cost ratio between 1.4 and 22.4. The positive benefit/cost ratio results are similar to the Dymond et al. (2013) study on indigenous forest in that both show the importance of valuing biodiversity. Soil and fertiliser management plans benefit aquatic ecosystems by reducing N in waterway; however, the use of nitrification inhibitors to lower N can have adverse effects on wetlands (Wilcock et al. 2008).

In total, 5 studies focused on changes in on-farm management practices. These studies either analysed the practices separately or bundled them together to show the cumulative effect. Monaghan et al. (2008) modelled the effects of 12 mitigation options on 4 different dairy farms, each in a different catchment. Few mitigations were cost effective on each of the four farms, highlighting the importance of needing to understand how different mitigations work in different places. The authors also found that the N focused mitigation options have a much more significant effect on reducing GHGs than the P focused mitigations.

Vibart et al. (2015) grouped mitigation options to reduce N and P loss into three groups: improved nutrient management, improved animal productivity, and restricted grazing. Simulating pastoral farming in Southland, they found that the first bundle of options, improved nutrient management and led to a reduction of N and P without losses in farm production. The improved animal productivity bundle achieved high levels of N reduction, but only minor levels of P reductions, while the last bundle provided the greatest levels of N reduction with little P reductions but had the highest cost to farmers. Decreases in stocking rate had a large effect on N. Soil drainage affected both N and P loss, with poorly drained soil losing less.

Daigneault and Elliot (2017) also grouped mitigation options into three groups: cost effective measures, less cost-effective options with large capital costs, and unproven, high cost options. Overall, bundles were specifically focused on N and/or P reductions and had little effect on GHG emissions. Only the options that decreased the stocking rate or increased vegetation resulted in large decreases in GHG emissions. Matheson et al. (2018) used similar mitigation bundles in their research in the Kaituna-Pongakawa-Waitahanui and Rangitaiki water management areas. When all bundles were implemented, they found significant reductions in N, P and GHG loss, but also found large decreases in profitability. The most cost-effective mitigation options were for dairy systems while drystock faming had higher cost mitigations due to a high capital cost. Lou (2017) looked at historical dairy and sheep and beef N and P management efforts to evaluate the effect of on-farm mitigation. They found only modest co-benefits from reductions in GHG when targeting N leaching and suggest that freshwater policy that focuses only on on-farm mitigations will have limited effects on GHG emissions.

It is important to note that each model varies in the level of information included on each mitigation. For instance, the OVERSEER model does not factor in inputs on management factors and farmers skills, which attribute to significant variation from observed results (Anastasiadis & Kerr 2013). This means that factors that are not included in the models can have a large effect on real world outcome. Not every mitigation will react identically on all farms. Monaghan et al. (2008) found differences in the effectiveness of the mitigation options they tested across four different dairy farms in four different catchments due to different physical resources and management systems.

In total, 2 studies focused on the impacts of dairy intensification on water quality and climate indicators. Vogeler et al (2015) modelled large scale conversion of sheep and beef farms into dairy in Southland. They found that while profits rise significantly (75%) due to the intensification, GHG gas emissions and N leaching increase (25% and 35% respectively). Foote et al. (2015) looked at the impacts of the national conversion towards more dairy farms and found that the dairy industry costs the country between $12.67 million and $3.1 billion in GHG emissions and $1.8-$10.7 billion dollars in N leaching.

Though not explicitly practice based, we included 4 studies that put monetary valuations on reductions in GHGs and improved water quality. Of those studies, 3 use choice experiments to estimate monetary valuations on improvement to ecosystem services, while another uses both a survey and a benefit transfer to estimate the value of improvements in ecosystem services in the viticulture industry. Baskaran et al. (2009,2009b) both used a nation-wide choice experiment to elicit responses of people’s willingness to pay for improvements in methane gas reductions, N leaching, irrigation reduction, and aesthetic value. However, Baskaran et al (2009a) looked exclusively at dairy farming while Baskaran et al. (2009b) analysed all pastoral farming. Overall, respondents in both studies were willing to pay for improvements in all four ecosystem services (see Appendix 4 for the full results from both studies). Takatsuka et al. (2009) focused on changes in N fertiliser use on arable crops, finding that households in New Zealand are willing to pay $209.92 a year for 50% reductions in GHG emissions and N leaching. Baskaran et al. (2010) using a choice experiment and benefit transfer found that respondents in the regions of Hawke's Bay and Marlborough are willing to pay $67.11 and $145.29, respectively, to reduce toxins from the wine industry from reaching groundwater, and $28.40 and $39.37, respectively, to reduce GHG from the wine industry by 30%. In all these valuation studies, the results are only valid within the setting or context of the research and they should not be applied to other settings without using rigorously proven benefit transfer approaches.

4 Conclusions

Research in New Zealand shows that climate and freshwater policies interact together. Actions taken to protect freshwater can have significant effects on GHG emissions and vice versa. Through a systematic literature review of New Zealand research, we identified 7 studies on the combined implementation of climate and freshwater policies. To broaden the scope of this report, we have included an additional 30 publications that are categorised into the following three groupings: studies that looked at the freshwater benefits of climate policy; studies that looked at the climate benefits of freshwater policy; and studies that focused on land management practices that are expected to have benefits for climate and freshwater conditions. The limited amount of studies in each category combined with the differing methodologies, scale, and scope means it is difficult to find consensus on the impacts of the policies and practices. Through the literature review, we have identified policies as limits or prices on nutrients or GHG emissions, whereas practices are individual or bundled changes to agricultural practice with the aim of reducing nutrients or GHG emissions or increasing carbon sequestration.

Though the search terms were chosen to ensure a robust study and to try to encompass all research carried out in this field some relevant literature might not have been found using these keywords. After the searches were concluded, we asked experts in this field to provide relevant publications to ensure robust results. We found 7 studies that fit the criteria of jointly assessing the impact of both climate and freshwater policy (Ausseil et al. 2019; Daigneault et al. 2012, 2018; Djanibekov et al. 2019; Greenhalgh et al. 2012; Neverman et al. 2019; Yeo et al. 2014). These studies showed that in order to meet the imposed GHG prices and nutrient limits, land use change was required to move away from pastoral farming. Depending on the study and the assumptions used in the model, net revenues either dropped or increased most probably due to land use type or land classification. These studies also showed that combining the two policies is more effective in addressing environmental issues than when the policies are implemented individually.

The remaining 30 studies included in this review either focus their analysis on just one of the policies or on land management practices. Results between these studies vary due to the diverse range of policy and methodological settings. The 2 studies focused on climate policy both found that GHG prices decrease GHG emissions, N and P leaching and net revenue (Daigneault et al. 2011; Morgan & Daigneault 2015). For the studies that model nutrient caps

(Daigneault et al. 2011, 2013, 2017a; Samarasinghe et al. 2011), each study found that adding nutrient caps successfully limits nutrients while lowering GHG emissions.

Most of the studies found in the literature search focus heavily on a small range of environmental and economic indicators. Whilst the indicators tracked are quite narrow, there would be other impacts which should be considered. For example, social and cultural impacts are likely to be important. We, however, did not find any studies that included these impacts, indicating a knowledge gap.

Appendix 1: Summary of joint climate and freshwater policy studies

Table 19: Description of studies on joint climate and freshwater policies

References	Climate policy settings	Freshwater policy settings	Scale	Land uses	Description of impacts
Daigneault et al. (2012)	GHG price: \$25/tCO$_2$e as of 2011	20% catchment level N leaching reduction	Hurunui-Waiau and Manawatu catchments	Dairy, sheep/beef, arable, forestry, scrubland, other pasture, Department of Conservation area	• A reduction in GHG emissions, N leaching and P loss, and increases in carbon sequestration • Decrease in pastoral area. Increase in forest, scrubland, arable and DOC areas • Economic impacts are marginal • Combining a GHG price with a nitrogen leaching reduction target have larger effects on land uses than considering policies separately
Greenhalgh et al. (2012)	GHG price: \$12.5/tCO$_2$e (as of 2010), \$25/tCO$_2$e	20% catchment level N and P leaching reduction	Hurunui-Waiau catchments	Dairy, sheep/beef, arable, forestry, scrubland, other pasture, Department of Conservation area	• The combination of policies results in greater reduction in GHG than the single policy, but no further decrease beyond the level set by nutrient leaching cap • GHG emissions reduce by about 25%, and net GHG emissions reduce by about 100% with \$25/tCO$_2$e and nutrient leaching cap • Increase in forestry, shrubland and arable. • Decrease in pastoral area, especially sheep and beef • About an 18% decrease in net returns from all land uses with \$25/tCO$_2$e and a nutrient leaching cap
Yeo et al. (2014)	GHG price: \$25/tCO$_2$e as of 2014	74% reduction in N leaching below the baseline N cap of 435 tN/year with trade scheme (N leaching price is determined by the model)	Lake Rotorua catchment	Dairy, sheep/beef, forestry	• GHG emissions reduce and N leaching targets are met when GHG price and N leaching trading policies are implemented together • To be economically viable, dairy becomes highly profitable but also N leaching intensive • N runoff targets are met by converting the entire area of sheep and beef into forestry, which makes dairy area unaffected

References	Climate policy settings	Freshwater policy settings	Scale	Land uses	Description of impacts
Daigneault et al. (2018)	GHG prices: $\$10/\text{tCO}_2\text{e}$, $\$20/\text{tCO}_2\text{e}$, $\$30/\text{tCO}_2\text{e}$	N leaching prices: \$10/kgN, \$20/kgN, \$30/kgN	National (including territorial authority results)	Dairy, sheep/beef, arable, horticulture, forestry, native, other land uses (e.g. other arable and horticulture)	• Area of sheep and beef reduces the most, followed by dairy. Area of arable, horticulture, forestry and other land uses increases. With the increase in GHG and N leaching prices pastoral area further reduces, while area of forestry and other land uses increases • Net revenues reduce with higher GHG and N leaching prices • GHG emissions and nutrient leaching reduce even with low GHG and nutrient prices, or with stand-alone policies • Substantial increase in carbon sequestration • Soil erosion also reduces with policies • Water yield reduces due to increase in forestry area
Ausseil et al. (2019)	GHG prices: \$0, \$288, $\$611/\text{tCO}_2\text{e}$ projected to 2065, and \$0, \$1,243, $\$2,641/\text{tCO}_2\text{e}$ projected to 2100 The GHG prices and freshwater policies are implemented together with different IPCC scenarios	20% catchment level N and P leaching and sediment load reduction	Kaituna catchment	Dairy, sheep/beef, arable, forestry, horticulture, scrubland, native, other pasture, other (e.g. urban, water)	• Reduction in GHG emissions, N leaching, P loss, soil erosion and water yield. Increase in carbon sequestration. • Decrease in pastoral, arable and horticulture areas. Increase in forestry, scrub and other land uses (urban, water). In one of the simulated IPCC scenarios, the area of sheep and beef increases • The overall agricultural and forestry net revenues increase. The total net revenues across land uses increase mainly due to carbon sequestration returns in pine forestry and projected increase in livestock commodity prices

References	Climate policy settings	Freshwater policy settings	Scale	Land uses	Description of impacts
Djanibekov et al. (2019)	GHG prices: \$40/tCO_2e in 2035, \$50/tCO_2e in 2050	5-m riparian buffers on each side of pastoral farming (no freshwater indicators)	National (including regional results)	Dairy, sheep/beef, arable, forestry, horticulture, native, other (e.g. urban, water), deer	• Decrease in pastoral area. Increase in forestry, arable and horticulture areas. • The overall agricultural and forestry net revenues decrease. The largest decrease in net revenues is for sheep and beef. All pastoral land uses have decreases in net revenues. The highest increase in revenue is for forestry due to carbon sequestration • Reduction in GHG emissions and increase in carbon sequestration. No physical outputs related to freshwater • Decrease in livestock number and production of commodities. Increase in production of timber, grains and horticultural products
	Combination also includes: the One Billion Trees Programme and the National Environmental Standard for Plantation Forestry				
Neverman et al. (2019)	GHG price: \$25/tCO_2e as of 2019 (only applied to carbon sequestered)	Sediment reduction targets for each catchment	National (including catchment and regional results)	Afforestation and whole-farm planning as land use mitigations on pastoral farms. Other land uses are not specified	• Of the land suitable for sediment mitigations almost 47% is afforested and 0.3% is allocated for whole-farm planning to meet the sediment reduction targets. The remaining land area did not require mitigations • Reduction in GHG emissions (by 34.5% annually), N leaching (by 1.3% annually), P loss (by 5.2% annually), and sediment load (by 13% annually). Increase in carbon sequestration (by 19.8 million tCO_2 annually) • Overall farm net revenue increases due to carbon sequestration revenues from the adoption of sediment reduction mitigations on farms (by 22% annually) • An increase in co-benefits (monetised environmental services) – avoided costs of dredging and sedimentation, as well as increase in carbon and water clarity benefits. Co-benefits net returns over 50 years range between \$5,404 and \$31,761 million depending on discount rate

Appendix 2: Summary of climate policy studies

Table 20: Description of studies on climate policy

References	Climate policy settings	Freshwater policy settings	Scale	Land uses	Description of results
Daigneault et al. (2011[9])	GHG prices: \$20, \$40/tCO_2e	N/A	Hurunui-Waiau catchments	Dairy, sheep/beef, arable, forestry, scrubland, other pasture (pigs), Department of Conservation area, deer	• At \$20/tCO_2e, net revenue for the catchment is reduced by 10% from baseline levels while GHG is reduced by 19% • At \$40/tCO_2e, net revenue is reduced by 16% while GHGs are reduced by 46% • N and P leaching also reduce with GHG price • With GHG prices, substantial area of pastoral land uses reduces, while area of forest, horticulture, arable and scrubs increase by more than 100% with \$40/tCO_2e
Morgan &Daigneault (2015)	GHG prices: \$0, \$20, \$40, \$60/tCO_2e	N/A	Hurunui-Waiau catchments	Dairy, sheep/beef, forestry	• Net revenue for the catchment is reduced by 1-2% from the baseline level depending on GHG price • Dairy area increases with low GHG price (\$20/tCO_2e), because its projected net revenue is higher (even with a carbon price) than sheep and beef and forestry. Dairy area decreases at the highest simulated GHG price (\$60/tCO_2e). • Forestry area increases due to GHG price at \$60/tCO_2e • Total GHG emissions decrease due to the GHG price, with net and gross emissions declining as the price of GHG increases • N leaching and P loss decrease due to the addition of a GHG price

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[9] There is another paper with a similar title by these authors. We have chosen the latest version of this conference paper from the Agricultural & Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting. The results from this version are different than those of earlier versions due to a difference in catchment productivity.

Appendix 3: Summary of freshwater policy studies

Table 21: Description of studies on freshwater policy

References	Climate policy settings	Freshwater policy settings	Scale	Land uses	Description of results
Daigneault et al. (2011)	N/A	Cap N and P at current levels. Trade of N and P allocated permits	Hurunui-Waiau catchments	Dairy, sheep/beef, arable, forestry, scrubland, other pasture (pigs), Department of Conservation area, deer	• Area of sheep and beef reduces the most followed by dairy. Instead of reduced pastoral area the area of forestry, horticulture and arable increase • Area of forestry more than doubles • GHG emissions decrease by 5% • Because of trade of N and P leaching among farmers, no reduction in nutrient levels • Net revenue increase of 6%
Samarasinghe et al. (2011)	N/A	15 %, 30 % N and P reduction targets	Hurunui Catchment	Dairy, sheep/beef, arable, forestry, horticulture, other (e.g. urban, water), deer	• Use both OVERSEER and SPASMO as biophysical models • At a 15% target, net revenue decreased between 0.5% and1.6% and GHG emissions decreased between 11% and14% • At a 30% target, net revenue decreased 2.4%–6.4% and GHG emissions decreased at least 22% • At both targets land use shifted from pastoral to arable crops and forestry
Strutt & Rae (2011)	N/A	10%, 20%, 30% N reduction target	National	Dairy	• N balance could be reduced by 10% with a 16% cut in nitrogenous fertiliser and a 5% fall in the stocking rate • Reducing fertiliser use and stocking rate by 31% and 11% respectively can reduce N balance by 20% for dairy • Reduction in fertiliser use by 45% and stocking rate by 19% can reduce N balance by 30% • Value added in dairy farm can fall by between 2% and 13%. Export earnings from dairy products may fall by between US$269 million and US$1,145 million

References	Climate policy settings	Freshwater policy settings	Scale	Land uses	Description of results
Daigneault et al. (2013)	N/A	45% decrease in N leaching	Hinds Catchment	Dairy, sheep/beef, arable, Horticulture, forestry, native	• The study assesses four types of policy approaches, as well as a baseline, to see if they can meet the 45% N leaching target • Most policies meet the 45% N leaching target, they also all decrease revenue • GHG emissions decrease for each policy scenario • Improving land management practices does not reach the target decrease in N leaching • Farm-specific caps lead to greater than desired decreases in N leaching, but also decreases in net revenue by 14% • Cap and trade policies reduced N leaching by 45% while dropping net revenue by 9–10%. This method also generated income for the council • The three hybrid policies modelled all met the 45% N leaching target while decrease revenue between 9% and12%
Duhon et al. (2015)	N/A	20% reduction in N through cap/trade	Lake Taupo	Dairy, sheep/beef	• As of 2012, the scheme has already purchased 128 tonnes of nitrogen which equals 14% of the 20% reduction goal • Farmers have been planting trees, which they can then gain carbon credits for as well as nitrogen credits
Daigneault et al. (2017a)	N/A	Varying targets for N, P and *E. coli* by council	National (including regional and catchment results)	Dairy, sheep/beef, arable, forestry, horticulture, native, other (e.g. urban, water), deer.	• Based on the survey results, the targets set by regional council are quite low. Most are to maintain status quo and not aimed at future reductions • Aggregate results are often greater than the targets because mitigation taken to target one contaminant may lead to co-benefits • Areas with high concentrations of dairy require greater reductions in N and P • All mitigation bundles decrease net revenue
MfE (2019)	N/A	Cap nutrients	National	Dairy, sheep/beef, arable, forestry, horticulture, other (e.g. urban, water), deer	• Nutrient cap reduces GHG emissions by 9 ktCO_2 in 2020 and by 786 ktCO_2 in 2035 • Decrease in dairy cattle number

Appendix 4: Summary of land management practice studies

Table 22: Description of land management practice studies

References	Practice	Scale	Land uses	Description of results
		Riparian		
Daigneault et al. (2017b)	Riparian buffer (5 m, 10 m, 20 m, 50m)	National (including territorial authority results)	Dairy, sheep/beef, arable, horticulture, forestry, native, other land uses (e.g. urban, water)	• Riparian margins lead to a reduction in N leaching and P loss of 50%-92% depending on buffer size • Biodiversity increases between 2% and 23% in naturally vegetated riparian strips • Carbon sequestration is improved in both active and natural regeneration, but lower in natural regeneration • Overall, riparian restoration generates net benefits between $1.7 billion and $5.2 billion per year
		Afforestation		
Dymond et al. (2012)	Afforestation	National	Low productivity land	• Afforestation reduce erosion • Afforestation creates significant carbon sinks. • Reduction of water yield between 30% and 50% is associated with new forests. • The net benefit of soil, water, and carbon in the North Island exceeded $400/ha/year, and in the South Island it exceeded $250/ha/year
Ausseil et al. (2013)	Afforestation	Manawatu catchment	Dairy, sheep/beef, forestry, deer	• The study simulates how ecosystem services would change due to hill country afforestation • Small change in GHG gas emissions compared with the baseline (0.6%), but a comparatively larger change in carbon sequestration (6.8%) compared to the baseline • Erosion control increased 19.9% due to the afforestation

References	Practice	Scale	Land uses	Description of results
Dymond et al. (2013)	Afforestation (Indigenous)	National	Pasture, scrublands	• Study showed that about 2 million ha of grassland with a benefit/cost ratio of 0.2 or more has the opportunity for indigenous forest restoration. About 0.7 million ha of shrublands can be protected to regenerate to indigenous forest • Averaged over 100 years, biodiversity, carbon sequestration and tourism benefits increase, while N leaching, erosion and water yield reduce. The magnitude of effects differs depending on location
Monge et al. (2016)	Afforestation	Farm level (dairy farm in Rotorua)	Dairy	• Considers farm risk aversion levels and various prices of carbon sequestration, payments for reducing N leaching by planting trees and N discharge allowance for dairy, drystock and forestry • Afforestation reduces uncertainty in incomes • At low risk aversion levels, farmers operate at levels below the maximum N allowance by including plantation forestry to a greater extent • At low N prices, risk-neutral farmers afforest less than half of the farm and operate at the maximum nitrogen allowance • At a high N price of $400/kg, forestry completely subsumes dairying
Walsh et al. (2017)	Afforestation	Manawatu catchment	Dairy, sheep/beef, arable, horticulture, forestry, native, other land uses (e.g. urban, water), deer, pig, other pasture	• Afforestation can provide substantial economic, carbon and water quality benefits, and the benefit-cost ratio of afforestation can be between 3:1 and 9:1 under different scenarios • Increase in water quality, carbon sequestration and biodiversity and decrease in GHG emissions with afforestation
Walsh et al. (2019)	Afforestation (Indigenous)	Gisborne	Exotic forestry, indigenous forestry	• Based on estimated benefits and costs the net present value of the indigenous forestry is negative, which is between $4 million and $21 billion. Losses are due to high costs of establishing indigenous forestry on exotic forestry area in Gisborne • Various potential environmental benefits can be achieved such as reduction in erosion and GHG emissions, improvement in water quality, and increase in carbon sequestration and biodiversity

References	Practice	Scale	Land uses	Description of results
		Individual on-farm management practices		
Monaghan et al. (2008)	Best management practices (optimum soil Olsen P level, deferred effluent irrigation, applying small amounts of effluent, Low rate effluent irrigation, bundling, low solubility P fertiliser, nitrification inhibitor, inclusion of low N feed in diet, low N input, restrict autumn/winter grazing, covered wintering pads, advanced pond system	Toenepi, Waiokura, Waikakahi, and Bog Burn catchments	Dairy	• Range of technological measures that can deliver substantial reductions in nutrient losses • P loss reductions with mitigations are between 28% (Bog Burn farms) and 52% (Waikakahi farms) • Applying no nitrogen fertiliser reduced GHG emissions by 17–31% • Nitrification inhibitor DCD can reduce nitrogen leaching by 9–30% and increase earnings before interest and tax by 9% • Cost of mitigations targeting P loss led to about 4% decrease from earnings before interest and tax
Anastasiadis & Kerr (2013)	Farm management	National	Dairy	• Improvements in N use efficiency can reduce leaching by >30% • Improvements in GHG use efficiency can reduce emissions by >15% • Production effect dominates the increase in GHGs but not N, leading to higher GHG use efficiency but lower N use efficiency. • By adjusting management practices production can increase significantly even if total N leaching is capped. • Winter grazing off raises N and GHG use-efficiencies
Doole & Romera (2015)	Stand-off pad	Farm level (Waikato)	Dairy	• Without a stand-off pad, production and profit decrease markedly when leaching is constrained. • In overall, with and without a stand-off pad GHG emissions increase with production and N leaching across production systems. • Stand-off pad reduces N leaching, while maintains milk production, especially for medium and high intensity dairy farms

References	Practice	Scale	Land uses	Description of results
Vibart et al. (2015)	Improved nutrient management, Improved animal productivity and restricted grazing	Southland	Dairy, sheep/beef	• Improved nutrient management leads to decrease to high N and P losses • Improved animal productivity provided additional N loss decrease but marginal P loss abatement • Restricted grazing has greatest N loss abatement but no additional P loss abatement • Sheep and beef and dairy farms have a low cost per N leaching reduction from improved nutrient management practice • Only dairy farms are responsive to GHG abatement, which was achieved by most intensified farms
Lou (2017)	N leaching management	National	Dairy, sheep/beef	• For dairy farms, 1% reduction in N leaching farmers are likely to reduce overall GHG by 0.11%. N_2O falls by 0.26% while CH_4 by 0.05%. • For sheep and beef, 1% reduction in N leaching leads to 0.10% decrease of overall GHG, almost zero for CH_4 and 0.41% for N_2O
Bundles of on-farm management practices				
Wilcock et al. (2008)	Afforestation, riparian, N budgeting, waste treatment technology	National	Dairy, sheep/beef	• Extensive afforestation results in lower specific yields (exports) of N, P, sediment and faecal matter and has benefits for stream habitat quality • Riparian afforestation does not achieve the same reductions in exports as extensive afforestation but can reduce concentrations of N, P, sediment and faecal matter • Soil and fertiliser management benefits aquatic ecosystems by reducing N exports but use of nitrification inhibitors DCD, to achieve this may impair wetland function to intercept and remove nitrate from drainage water, or even add to the overall N to waterways • Waste management can achieve 21-fold reduction in GHG emissions

References	Practice	Scale	Land uses	Description of results
Daigneault & Elliot (2017)	Bundles (cost effective measures, less cost effective with large capital costs, large cost and unproven)	National	Dairy, sheep/beef, deer, arable, horticulture	• As many mitigation bundles considered in the just focused on N and/or P, they do not have a large effect on GHG emissions • De-stocking, DCDs, or additional trees or vegetation have large effects on GHG emissions • Implementing some mitigation bundles could lead to an increase in GHG emissions • Mitigation bundle that is low cost (0–11% reduction in farm net revenue) presents a wide range of effectiveness for contaminants
Matheson et al. (2018)	Bundles (low cost and low barrier to adoption, moderate barrier and direct cost, and high barrier and high cost	Kaituna-Pongakawa-Waitahanui and Rangitaiki Water Management Areas	Dairy, sheep/beef, deer, arable, kiwifruit and forestry	• Dairy farms that adopted all mitigation bundles reduced N leaching by 44%, P loss by 21% and GHG emissions by 17% while reducing profit by 35% • Drystock farms that adopted all mitigation bundles reduced N leaching between 14% and 35%, P loss between 0% and 38% and GHG emissions between 8% and 34% while reducing profit by between 53% and183%
		Intensification of agricultural land		
Vogeler et al. (2014)	Dairy Intensification	Southland	Dairy	• This study models what would happen if there was largescale conversion of sheep and beef in Southland to dairy (increasing dairy land area from 16%-45% • Profit in the region would increase by 75% • GHG emissions increased by 25% and N leaching increased by 35%
Foote et al. (2015)	Dairy Intensification	National	Dairy	• The study gives the estimated annual costs of impacts of the dairy industry • Removing nitrates from drinking water due to dairy is estimated at between $1.8 and $10.7 billion a year • The cost of national dairy GHG emissions due to dairy is estimated between $12.67 million and $3.1 billion a year

References	Practice	Scale	Land uses	Description of results
		Economic valuation studies of ecosystem services		
Baskaran et al. (2009a)	Dairy intensification reduction Methane reduction (10%, 30%), N leaching (10%, 30%), Water usage for irrigation reduction (10%, 30%)	Canterbury	Dairy	• Study uses surveys, choice modelling and marginal willingness to pay methods to estimate values of ecosystem services • Respondents are on average willing to pay $15.85/person/year for a 30% reduction in CH_4 emissions • Respondents are on average willing to pay $31.82/person/year for a 30% reduction in N leaching • Study shows willingness to pay to reduce GHG emissions and N leaching differs by income levels of respondents • To reduce GHG emissions by 30% respondents with incomes lower than $40,000 and higher than $70,000 are willing to pay $9.62/person/year and $68.04/person/year respectively
Baskaran et al. (2009b)	Pastoral intensification Methane reduction (10%, 30%), N leaching (10%, 30%), Water usage for irrigation reduction (10%, 30%)	National	Pastoral	• Study use the choice experiment to value the changes in methane reduction, N leaching reduction, irrigation reduction and aesthetic value • Overall, respondents were willing to pay for each of the four ecosystem services • Respondents were willing to pay $6.66/person/year for 5 years for a 10% reduction in methane and $22.14/person/year for a 30% reduction in methane • Respondents were willing to pay $11.83/person/year for 5 years for a 10% reduction in N leaching and $38.55/person/year for a 30% reduction in N leaching • Respondents were willing to pay $8.33/person/year for 5 years for a 10% reduction in water usage for irrigation and $8.90/person/year for a 30% reduction in water usage for irrigation • Respondents were willing to pay $17.61/person/year for 30% more scenic views

References	Practice	Scale	Land uses	Description of results
Takatsuka et al. (2009)	GHG (50%), N leaching (50%) reductions	National	Arable	• Surveys, contingent valuation and choice modelling methods to estimate values of ecosystem services • A 50% reduction of GHG emissions are valued at \$192.51/household/year and \$86.03/household/year in Canterbury and the rest of New Zealand respectively • A 50% of N leaching reduction are valued at \$87.73/household/year and \$79.03/household/year in Canterbury and the rest of New Zealand respectively • Willingness-to-pay for the respondents' most preferred by respondents' policy combination is \$245.02/household/year for Canterbury and \$209.92 /household/year for the rest of New Zealand
Baskaran et al. (2010)	30% reduction in GHG, 0 GHG per ha, removal of toxins from groundwater,	Hawkes' Bay, Marlborough	Viticulture	• Study uses surveys, benefit transfer, choice experiment and willingness to pay • To remove toxic chemicals from reaching groundwater, respondents are willing to pay \$67.11/household/year and \$145.29/household/year in Hawke's Bay and Marlborough respectively • To reduce GHG emissions by 30%, respondents are willing to pay \$28.40/household/year and \$39.37/household/year in Hawke's Bay and Marlborough respectively
		Other		
Soliman & Djanibekov (2018)	GHG, N and P leaching and economic efficiency of farm management and agro-ecological conditions	Waikato/Bay of Plenty, Canterbury, Lower North Island, Northland, Southland, Taranaki	Dairy	• GHG emissions, N and P leaching are excessive and inefficient • On average, a reduction of 27% in GHG emissions and N and P leaching is achievable while maintaining the same level of economic output • On average, dairy farm can reduce GHG emissions by 3.3 tCO2e/ha/year, N leaching by 14 kg/ha/year and P loss by 0.7 kg/ha/year • Eco-efficiency score (the best is 1) of GHG is 0.72, N leaching is 0.46 and P loss is 0.39 • Irrigation and on-farm management practices can improve efficient outputs of GHG as well as N and P losses • Soil topography and higher temperatures have the most adverse effects on dairy farm eco-efficiency

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