Economic Impacts of GHG and Nutrient Reduction Policies in New Zealand: A Tale of Two Catchments*

Dr. Adam Daigneault
Landcare Research
Auckland, New Zealand
daigneaulta@landcareresearch.co.nz

Dr. Suzie Greenhalgh
Landcare Research

Oshadhi Samarasinghe
Landcare Research

Paper prepared for the AAEA Organised Symposium at the 56th Annual Australian Agricultural and Resource Economics Society Annual Meeting, Fremantle, Western Australia, 8-10 February, 2012

---

[*] This research was made possible by generous funding from NZ Ministry of Agriculture and Forestry (MAF) and the NZ Ministry of Science and Innovation (MSI). Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of MAF or MSI. The authors also wish to acknowledge the assistance of Stuart Ford and Steve Green for their tireless effort in helping collect the data for this paper and Elizabeth Marshall of USDA Economic Research Service for her significant contribution to model development.

ABSTRACT

Agricultural and forestry GHG emissions are a key feature of New Zealand's emissions profile, and New Zealand is the only country, to date, to have indicated that agricultural and forestry emissions will be covered under their domestic climate policy – the New Zealand Emissions Trading Scheme. Coupled with climate policy development is the increasing scrutiny of agricultural impacts on water. This paper uses New Zealand Forest and Agriculture Regional Model (NZ-FARM) to assess the potential economic and environmental impacts of imposing both a climate and nutrient reduction policy on the agricultural and forestry industries in the Manawatu and Hurunui/Waiau catchments in New Zealand. We find that adding a scheme that reduces catchment-level nutrients by 20% on top of a national policy that puts a price of $25 per ton carbon dioxide equivalent on agricultural GHG emissions could result in greater environmental benefits at a relatively small cost, but the converse is not always true and could be significantly more costly for landowners.

KEYWORDS: Agriculture and forestry modelling, land use, climate policy, water quality, greenhouse gas emissions, nutrient leaching

INTRODUCTION

Agriculture is an important part of New Zealand’s economy, and the sector faces similar challenges as other large producing countries of the world as it strives to maintain or enhance the level of output while keeping its resource use and environmental integrity in check. Agricultural production in most parts of the country has increased significantly in recent decades through the use of additional inputs, including fertilizer, irrigation, and supplemental feeds. Intensifying agricultural inputs has increased nutrient leaching levels and sediment runoff to lakes, rivers and streams, putting additional strain on the country’s freshwater resources. Approximately 47% of New Zealand’s total greenhouse (GHG) emissions occur in the agricultural sector, which is relatively high compared to other developed countries in the world, (MfE, 2011).

The country is unique from a regulatory perspective as it implemented a climate policy in 2008, the New Zealand Emissions Trading Scheme (ETS), which already covers many major sectors of the economy, including forestry. Discussions are on-going about the most appropriate way to bring the agricultural sector into the ETS in 2015 to help meet national emissions targets without placing a large burden on its stakeholders. As of early 2012, agriculture’s primary points of obligation will be the meat, wool and dairy processors. Processing companies are likely to adopt a number of measures to pass that obligation upstream to the farming community, so farmers can expect to face a carbon price, albeit indirectly though the processors. In addition, farmers also are subject to a carbon price through, for example, higher fuel prices as fuel suppliers pass on the cost of their climate obligations to consumers.

At the same time, as in many countries, New Zealand farmers are also facing increasing pressure from actions to reduce their contribution to water quality degradation in many catchments around the country through environmental regulation. Water quality, particularly nitrogen pollution and to a lesser extent phosphorous pollution, has either been recognized as a problem or there are concerns about the rate of water quality decline. This has led to a growing number of regional authorities starting processes to limit nutrient losses to waterways. Regional councils, under New Zealand’s Resource Management Act (1991), hold the responsibility for managing catchment water quality and many other natural resources. A few catchments already have nutrient limits in place through Regional Plans (e.g., Lake Taupo and Lake Rotorua catchments), with many more in the process of identifying or beginning processes to identify water quality limits and policies to achieve such limits. The central government has also recently announced plans to increase funding for both regional irrigation projects and efforts to clean up waterways (Carter 2011, NZ Government 2011, Smith 2011). However, debate exists as to whether agricultural emissions reduction and water quality policies such as limiting nutrient leaching levels can be met while still maintaining economic viability and anticipated gains in agricultural productivity.

Given that farmers are facing a carbon price through national policy, and many are also likely to face nutrient limits through regional policy, any assessment of the impact of either a domestic climate policy or nutrient limits should be considering these impacts simultaneously, not independently. The purpose of this paper is to understand the implications on farm income, land use and the environment when farmers are faced with multiple environmental constraints, as well as the interaction between climate and water policy and the extent to which water policy can be used to meet climate obligations and vice versa.

This paper uses an agro-environmental catchment model to assess potential economic and environmental impacts of a climate change and nutrient reduction policy on land-based production in two New Zealand catchments.   We use the Hurunui and Waiau catchments in the North Canterbury region of New Zealand's South Island and the Manawatu catchment on the North Island for this analysis as both regions are currently undergoing a process to set nutrient limits from agricultural production that could require farmers to change their land management to meet reduction targets.

Despite the importance of the agricultural and downstream processing sectors in the New Zealand economy, there is not a strong tradition of using partial or general equilibrium models to evaluate domestic policies or other measures directed at the agricultural sector. Policy-makers have instead relied on the development of ad hoc scenarios of land use change, farm budget models, and simple multiplier analysis of flow-on effects. To redress this situation, we have developed the New Zealand Forest and Agricultural Regional Model (NZ-FARM), a catchment-level agro-environmental economic model. Catchment-level economic models are important for appropriately addressing detailed regional impacts and identifying the synergies between climate change and water quality. Partial equilibrium models are often preferred for catchment-level analyses as they detailed quality representation of practices, economics and environmental impacts for the sectors being modelled, in this case the agricultural and forestry sectors (Johanssen et al. 2007; Adams et al. 1996).

There have been few studies that have comprehensively assessed the economic and environmental impacts of regulatory policy on land use in the New Zealand context. Monaghan et al. (2008) analyse the effectiveness of best practice management for reducing nutrient losses from dairy farms in four major catchments of New Zealand. Anastasiadis et al. (2011) use the N-Manager simulation model to estimate the economic costs and environmental impacts associated with six approaches to nutrient management in the Rotorua catchment. Hendy et al. (2006) use a partial equilibrium model to simulate the effects of a tax on agricultural emissions and a payment for native forest and scrub regeneration on land use nationally. Although useful for policy analysis, the models used in these studies do not provide estimates at the level of detail available using NZ-FARM. NZ-FARM is also unique because, to our knowledge, it is the only model in New Zealand capable of assessing the impact of policy or technological changes on rural incomes for a wide array of environmental performance indicators, such as GHG emissions and sequestration, water quality and soil loss.

The paper is organized as follows. First, we present the theoretical foundation of the NZ-FARM model, and describe the details of the data sources specific to the two catchments. Next, we describe the GHG and nutrient mitigation options for the two catchments. Following that, we present baseline land use, farm production, GHG emissions, water use, and other environmental outputs, followed by results from a series of environmental policy scenarios. The final section provides a conclusion of our findings.

METHODOLOGY

Agro-Environmental Economic Model

The New Zealand Forest and Agriculture Regional Model (NZ-FARM) is a comparative-static, non-linear, partial equilibrium mathematical programming model of New Zealand land use operating at the catchment scale. Its primary use is to provide decision-makers with information on the economic impacts of environmental policy as well as on how a policy aimed at one environmental issue could affect other environmental factors. It can be used to assess how changes in technology, commodity supply or demand, resource constraints, or farm, resource, or environmental policy could affect a host of economic or environmental performance indicators that are important to decision-makers and rural landowners. The model can track changes in land use, land management, N leaching, and P leaching from imposing a variety of policy options that range from establishing a catchment-level cap and trade programme to imposing nutrient leaching constraints at the enterprise-level. A detailed schematic of components of NZ-FARM is shown in Figure 1.

The model's objective function is to determine the level of production outputs that maximize the net revenue (π) of production across the entire catchment area, subject to land use and land management options, agricultural production costs and output prices, and environmental factors such as soil type, water available for irrigation, and regulated environmental outputs (e.g., nutrient leaching limits) imposed on the region. This is specified as:

$$\text{Max NR} = \sum_{r,s,l,e,m,io} \begin{array}{c} \text{Output Price*Output Quantity} \\ -\text{ Livestock Input*Unit Cost} \\ -\text{ Variable Cost*Units Used} \\ -\text{ Annualized Fixed Cost} \\ -\text{ Environmental Tax} * \text{Units Emitted} \\ -\text{ Land Conversion Cost*Hectares Converted} \end{array} \tag{1}$$

subject to:

$\text{NR}_{r,s,l,e,m} \geq 0$

$\text{Land Use}_r \leq \text{Land Available}_r$

$\text{Water Available for Irrigation}_r \leq \text{Irrigated Area}_r$

$\text{Environmental Output}_r \leq \text{Regulated Environmental Output}_r$

where *r* is the catchment region, *s* is soil type, *e* is enterprise, *l* is land use type , and *m* is land management practice, and *io* is a set of enterprise-specific input costs, output prices, and environmental outputs. Summing the revenue and costs of production across all enterprises and regions yields the total net revenue for the catchment. Regions within a catchment are differentiated by land use classification, such that all land in the same region will yield the same level of productivity for a given enterprise and land management scheme. A formal mathematical representation of the model is listed in Appendix A.

In addition to estimating economic output from the agriculture and forest sectors, NZ-FARM also tracks a series of environmental factors including N and P leaching, GHG emissions, water yield, and soil erosion. Simulating endogenous land management is an integral part of the model, which can differentiate between ‘business as usual’ (BAU) farm practices and less-typical options that can change levels of agricultural output, nutrient leaching, and GHG emissions, amongst other things. Key land management options tracked in the model include changing fertilizer regimes and stocking rates, adding an irrigation system or implementing mitigation technologies such as the installation of a dairy feed pad or the application of nitrogen inhibitors (DCDs). Including a wide range of management options allows us to assess what levels of regulation might be needed to bring new technologies into general practice. Details on the specific land management, economic, and environmental factors tracked in this paper are described in the data section.

The optimal distribution of soil $\text{type}_{1\ldots i}$, land $\text{use}_{1\ldots j}$, $\text{enterprise}_{1\ldots k}$ land $\text{management}_{1\ldots l}$, and agricultural $\text{output}_{1\ldots m}$ in a particular region are simultaneously determined in a nested framework that is calibrated based on the shares of current land use in the region. At the highest levels of the nest, land use is distributed over the region based on the fixed area of various soil types. Land use is then allocated between several enterprises such as arable crops (e.g., wheat or barley), livestock (e.g., dairy or sheep and beef), or forestry plantations that will yield the maximum net return. A set of land management options (e.g., stocking rate, fertilizer regime, etc.) are then imposed on an enterprise which then determines the level of agricultural outputs produced in the final nest. Figure 2 shows the potential nest for an irrigated dairy farm that uses a feed pad and produces a series of outputs from pasture grown on Balmoral soil.

The allocation of land to a specific soil type, land use, enterprise, land management, and product output is represented with constant elasticity of transformation functions (CET). The transformation function essentially specifies the rate at which regional land inputs, enterprises, and outputs produced can be transformed across the array of available options. The CET functions are calibrated using the share of total baseline area for each element of the nest and a parameter, σ_i, where $i \in \{s, l, e, m, p\}$ for the respective soil type, land use, enterprise, land management, and product output. CET parameters can theoretically range from 0 to infinity, where 0 indicates that the input is fixed, while infinity indicates that the inputs are perfect substitutes. The CET functions used in NZ-FARM are parameterized based on the estimates from existing literature of regional economic land use models (e.g., Johansson *et al.* 2007, Adams *et al.* 1996, Hendy *et al.* 2006). The elasticities in the model ascend with each level of the nest between land use and land management, as there is typically more flexibility to transform the enterprise mix compared to altering the share of land use or to shift land use across soil types. The CET parameter for soil (σ_S) is set be 0, as the amount of a particular soil type in a region is fixed. In addition, the parameter for agricultural production (σ_P) is also assumed to be 0, implying that a given enterprise and management option produces a fixed set of outputs.

The model is written and maintained in General Algebraic Modelling System (GAMS), and the baseline calibration and scenario analysis are derived using the non-linear programming (NLP) version of the COIN IPOPT solver (GAMS 2011).

Study Area and Data Sources

Data for the inputs used for the catchments in NZ-FARM were obtained from several sources. A list of all the different sets for which data was obtained for the Hurunui and Waiau catchment (enterprise, soils, etc.) is shown in Table 1[1]. Sources of these data are discussed in the following subsections. In total, there are nearly 1200 combinations of enterprise, input, and land management options modelled for the Hurunui/Waiau catchment and 800 combinations for the Manawatu catchment.

---

[1] The list of enterprises presented in Table 1 differs slightly for the Manawatu catchment, but aggregated categories discussed in this paper (e.g., Forest, Arable, Dairy, etc.) remain the same.

Geographic Area and Land Use

This paper focuses on the Hurunui/Waiau catchment in North Canterbury and the Manawatu catchment in the North Island. A map of each catchment is shown in Figures 3a and 3b. The catchment area is divided into sub-catchment zones based primarily on biophysical properties derived based on LUC classes from New Zealand Land Resource Inventory (NZLRI) data and availability of water for irrigation. These areas include the plains, foothills, and hills for Hurunui/Waiau and flats and hills for Manawatu. The Manawatu is further disaggrated by the Tararua ranges on the eastern side of the catchment. Each region contains by five distinct land uses: forest, arable, pasture, scrub, and natural/Department of Conservation (DOC) land.

Enterprises, Inputs, Outputs and Prices

The model tracks all the major land uses and enterprises in each catchment. Key enterprises include dairy, sheep, beef, deer, timber, maize, wheat, and fruit. NZ-FARM tracks 18 enterprises for the Hurunui/Waiau catchment and 16 for the Manawatu catchment. Every catchment zone has a subset of these practices that can be undertaken though, which is restricted by the enterprises undertaken in the baseline scenario. These sets are determined by bio-geographical characteristics like slope, soil type, access to water, etc., as well as the enterprises shown in most recent land use maps. The spatial distribution of the baseline enterprise mix for the each catchment is shown in Figures 4a and 4b.

Each enterprise requires a series of inputs to maximize production yields. The high cost of given inputs coupled with water and input constraints can limit the level of output from a given enterprise. Outputs and prices are primarily based on data provided by Lincoln University (Lincoln University, 2010), Ministry of Agriculture and Forestry (MAF) farm monitoring report (MAF, 2010a), and the 2010 Situation and outlook for New Zealand Agriculture and Forestry (MAF, 2010 b), and are listed in 2009 New Zealand dollars (NZD). Stocking rates for pastoral enterprises were established to match figures included in the FARMAX model (Bryant et al., 2010). The physical levels of fertilizer applied were constructed from a survey of farmers in each catchment.

Specific enterprises also face a large set of fixed and variable costs ranging from stock replacement costs to deprecation that were obtained from personal communication with farm consultants, the MAF farm monitoring report (MAF, 2010a) and Lincoln University (Lincoln University, 2010). The cost series was developed for each enterprise and varied across all regions for both catchments. Altering the cost of inputs or price of outputs as well as the list of enterprises available for a given region will change the distribution of regional enterprise area, but the total area is constrained to remain the same across all model scenarios.

Environmental Outputs

Data on environmental output coefficients were obtained from several sources including, but not limited to, output from the OVERSEER and SPASMO models and findings from the literature. N and P leaching rates for all pastoral enterprises in Hurunui/Waiau were taken from OVERSEER (2010), while N and P leaching rates for grains and horticulture were constructed using SPASMO (Clothier et al., 2008). All livestock N and P leaching estimates for Manawatu pastoral and arable crops were derived using OVERSEER[2]. Values for N leaching from pine plantations and native vegetation for both catchments were taken as an average from the literature (e.g., Parfitt et al 1997; Menneer et al 2004). We assumed that no P leaches from plantations or native forest lands.

GHG emissions for most enterprises were derived using the same methodology as the New Zealand GHG Inventory (NZI), which follows the IPCC's *Good Practice Guidance* (2000). Pastoral emissions were calculated using the same emissions factors as the NZI, but applied to per hectare stocking rates specific to the catchment. Forest carbon sequestration rates were derived from regional lookup tables (Paul et al., 2008). All emission outputs are listed in tons per CO_2 equivalent. To be consistent with the inventory (MfE, 2011), we convert all emissions CO2e using the same 100 year global warming potentials of 21 for CH_4 and 310 for N_2O.

ENVIRONMETNAL POLICY SCENARIOS

The current ETS in New Zealand covers all major sectors of the economy, with the exception of agriculture that is due to be regulated in 2015. Besides forestry, most emissions are covered through an upstream point of obligation on fossil fuels. For this analysis, we impose a climate policy on agriculture through a unit price per tonne of GHG emissions ($/t$CO_2$e) for all farm inputs (e.g., fertilizer), livestock activity (e.g., beef and sheep grazing), and energy used in primary production (e.g., fuel for tractors and electricity for irrigation). All activities conducted outside the farm gate, such as the production of fertilizer or transportation of output to the processing plant, are not covered in this analysis. The maximum price of a New Zealand Unit[3] (NZU) in 2011 was capped at $25, and many sectors were only obligated to trade in one NZU for each two units of emissions. For this analysis, we restrict the climate policy scenarios to the same GHG price level of $25/t$CO_2$e. For the baseline calibration, we assume that there is no price imposed on emissions from agricultural production, but landowners do face increased costs of electricity and fuel used as farm inputs. Additionally, forestry activities are allowed to receive credits for carbon sequestration in all scenarios.

---

[2] The sole exception for Manawatu is potatoes, which used SPASMO estimates

[3] One NZU is equivalent to one tonne CO2e of GHG emissions

BASELINE AND SCENARIO ANALYSIS

Baseline

The Hurunui/Waiau catchment comprises nearly 582,000 ha, of which about 22,000 ha are irrigated. Almost all of the catchment's irrigation occurs in the plains region, as that is typically the area with the highest productivity and revenue potential. Total catchment income derived from baseline figures for input costs, output prices, and current enterprise productivity is estimated at $250 million NZD. The aggregate area for major enterprise types for each region is listed in Table 2, while regional output is shown in Table 3. Dryland sheep and beef farming dominate the region, especially in the hills and foothills. A majority of the dairy production currently takes place in the plains region, as it is heavily reliant on access to water. With exception of some forest plantations in the foothills, nearly all of the non-sheep and beef production in the catchment occurs on the plains region that has greater access to irrigation and overall better growing conditions.

The Manawatu catchment comprises nearly 576,000 ha, of which only 6,000 ha are irrigated for dairy production. Total catchment income is estimated at $308 million. Pastoral enterprises dominate the region, especially dryland sheep and beef farming. As with Hurunui/Waiau most of the dairy production takes place in the more productive flats region. Unlike the other catchment in this paper, Manawatu constitutes very little area of forest, scrub, or natural/DOC land (aggregate of 23%). Additionally, about 6,500 ha (1%) are used to produce arable crops such as maize, barley, wheat, and potatoes.

The total and net GHG emissions for the two catchments are listed in Table 4 and are estimated to be about 1,531,000 tCO_2e for Hurunui/Waiau and 3,156,000 tCO_2e for Manawatu. The bulk of emissions come from non-CO_2 gases in the livestock sector, which is typical for most agriculture-intensive catchments in New Zealand. The GHG emissions for Manawatu are much larger than Hurunui/Waiau because a higher proportion of land is designated as pasture (77% v. 46%). As in the latest national GHG Inventory (MfE 2011), CH_4 from enteric fermentation is the largest source of emissions, followed by N_2O from grazing land. Annual carbon sequestration from native vegetation on scrub and DOC land reduces net emissions[4] in the Hurunui/Waiau catchment by about 40% and emissions in the Manawatu by 32%. Total leaching levels are estimated at 3040 tons N and 45 tons P for Hurunui/Waiau and 5770 tons N and 370 tons P for Manawatu. These equate to about 5.2 kgN/ha and 0.1 kgP/ha for Hurunui/Waiau and 10.0 kgN/ha and 0.6 kgP/ha for Manawatu. Figures differ greatly across the two catchments, as well as in the regions within each catchment due to the different distributions in soil type, land use classification, and enterprise mix.

---

[4] Note that in the baseline of this static model, we assume that all plantations immediately replant the area that is harvested, and thus the baseline amount of forest carbon sequestration for pine is zero.

Policy Scenarios

The following sections discuss the findings from the policy scenarios for the Hurunui/Waiau and Manawatu Catchments with two sets of GHG emissions prices on land-based production. The initial scenario is a stand-alone climate policy (AgETS) that imposes a GHG price of \$25 per tCO_2e on GHG emissions for all stages of production at the farm level. For forest plantations, landowners receive a credit for carbon sequestered beyond the baseline from changes in forest management or adding new plantations, but must submit a payment for felling trees and converting to another land use. The second scenario illustrates a nutrient reduction and water quality improvement policy (Nutrient) by imposing a comprehensive cap on N leaching and P loss for the catchment at 20% below the baseline levels. Because the cap on nutrient leaching is set at the catchment level, it allows landowners to trade nutrient leaching loads across enterprises and farm management practices to meet a comprehensive target for the region. This is more flexible and cost effective than all landowners meet individual targets, and is consistent with both existing and proposed nutrient trading programmes in New Zealand (Environment Waikato 2009). The third scenario is a dual environmental policy (AgETS_NUT) that places both a price of \$25/tCO2e on agricultural GHG emissions and a catchment-level cap of nutrient loads at 20% below the baseline levels. The change in key outputs tracked by NZFARM such as net revenue, GHG emissions, and nutrients relative to the baseline are listed in Table 5, while the percentage change in enterprise area for each policy is shown in Figure 5. Finally, the breakout of GHG emissions from the catchment for each scenario is shown in Figure 6.

Hurunui/Waiau Estimates

With the AgETS policy, net revenue for the catchments is reduced by \$33.2 million (-13%) while GHGs are reduced by 406,000 tCO_2e (-26%). Land use shifts from dairy and sheep and beef to lower emitting enterprises such as arable, scrubland and forests. A co-benefit of the GHG policy is that N and P are reduced by about 11% and 6%, respectively.

For the nutrient policy net revenue is estimated to decline by 5% from baseline levels while GHGs are reduced by 22%. Total N and P are both reduced to precisely the cap level of 20%. Enterprise change for the stand-alone nutrient policy is similar to the AgETS policy such that landowners are expected to shift from intensive pasture to forest, arable, and scrubland. Some sheep and beef and dairy land is also expected become fallow, as indicated by the increase in 'other pasture'.

The dual environmental policy scenario (AgETS_NUT) would result in slightly higher revenue impacts as the AgETS case (-15%), but with greater impact on the environmental indicators. GHG emissions could be reduced by as much as 34% compared to the baseline level while simultaneously reducing total N and P levels in the catchment by 20%. These findings suggest that if the agricultural climate policy were to be carried out as planned, going forth with a nutrient reduction policy in the Hurunui/Waiau region at the same time could result in additional environmental benefits without dramatically larger economic impacts. This is because when farmers are forced to consider their GHG emissions and nutrient levels at the same time, they can choose the land use and land management option that increases an array of environmental benefits at the least cost to their financial returns.

Manawatu Estimates

Net revenue for the Manawatu catchment is estimated to be reduced by $60.8 million (-20%) for the AgETS scenario, while GHGs are reduced by 1.3 million tCO_2e (-40%). As with Hurunui/Waiau, land use shifts from dairy and sheep and beef to arable, forests, scrub, and fallow land, but about twice as much land in the Manawatu is expected to change. The increase in forests and scrubland leads to an increase in carbon sequestration, reducing total net GHGs to just 0.3 million tCO_2e. Unlike the Hurunui/Waiau catchment, this change in land use does not necessarily lead to a reduction in the levels of nutrients in the region. Estimates show that P loss could be reduced by about 38% because of the reduction in the number of animals grazing on the land, but N leaching levels are expected to increase by more than 3150 tons (55%), primarily because of the expansion of N-intensive arable cropping like maize.

Estimates for the nutrient scenario found that net revenue in Manawatu declines by just 1% from baseline levels while GHG emissions are reduced by 16%. Total N and P leaching are both reduced to the cap level of 20% below baseline levels. Landowners are still expected to shift from pasture to forest, arable, and scrubland, but at levels much lower than seen in the AgETS scenario and more in line with the expected land use change in the Hurunui. This suggests while a stand-alone nutrient policy in the Manawatu does not produce the same level of reductions in GHG emissions as the AgETS policy, the fact that it provides multiple environmental benefits at a relatively low cost to the landowner could make it a more viable option to pursue in the region.

The dual environmental policy scenario (AgETS_NUT) would result in similar revenue impacts as the AgETS case (-21%), but without the large increase in N leaching from the expansion of arable crops. GHG emissions could be reduced by as much as 32% compared to the baseline level while simultaneously reducing total N leaching by 20% and P loss by 29%. The enterprise mix is estimated to shift predominantly to fallow land, forest and scrubland, with just a slight increase in arable crops. This suggests that an additional policy or restriction might have to be put in place to ensure that water quality standards in the catchment are at least maintained. As with the Hurunui/Waiau, we find that if a national level agricultural climate policy were to be carried out as planned, going forth with a nutrient reduction policy in the Manawatu region at the same time could result in additional – perhaps substantial – environmental benefits without dramatically larger economic impacts on landowners in the area.

CONCLUSION

This paper uses an economic catchment model, NZ-FARM, to assess changes in land use, agricultural output, and environmental factors from a series of environmental policies on the Hurunui/Waiau and Manawatu catchments in New Zealand. We investigate the potential impacts of imposing a GHG price on farm-level activities, placing a nutrient loading cap at the catchment-level, or implementing both a climate change mitigation and nutrient reduction policy on landowners at the same time.

Our estimates suggest that there are potentially large trade-offs between economic returns for the agricultural sector and environmental benefits in the catchments when various environmental policies are considered, but the level of reduction in returns can vary across policy and catchment. We also found that directional changes in land use were relatively consistent regardless of the environmental policy or catchment. The added cost of GHG- or nutrient-intensive agricultural production induced shifts from pastoral enterprises to arable land and forests, but not all enterprises are expected to change by the same relative magnitude across all catchments and policies. Some of these changes in land use could result in negative outcomes for environmental metrics outside the scope of the policy. This was particularly the case in the Manawatu when imposing a stand-alone AgETS policy was estimated to increase N leaching levels by more than 50% over the baseline, primarily because of the expansion of N-intensive arable cropping. This suggests that an additional policy or restriction might have to be put in place to ensure that water quality standards in the catchment are at least maintained.

Finally, this paper found that adding a nutrient reduction policy on top of a price on agricultural GHG emissions could result in greater environmental benefits with relatively small additional economic costs. This is because when farmers are forced to consider their GHG emissions and nutrient levels at the same time, they can choose the land use and land management option that increases an array of environmental benefits at the least cost to their financial returns. This suggests that policymakers should continue with their plan to impose water quality improvement measures at the regional level, even if a national agricultural GHG emissions reduction policy is expected to come online in 2015. Further research needs to be conducted to determine if the findings for the Hurunui/Waiau and Manawatu catchments investigated in this study are consistent for other major farming regions of New Zealand and the potential impacts of adding or removing different mitigation practices from the suite of options included in this modelling exercise. Further work should also be conducted on the impact of imposing different nutrient reduction caps, GHG emissions prices, or nutrient permit allocation schemes on the two catchments.

REFERENCES

Adams D, Alig R, Callaway J, McCarl B, Winnett S. 1996*. The Forest and Agriculture Sector Optimization Model (FASOM): Model structure and policy applications.* USDA, Forest Service, PNW Research Station, General Technical Report PNW-RP-495, Portland, USA.

Anastasiadis, S., Nauleau, M-L., Cox, T., Kerr, S., Rutherford, K. 2011. Nutrient Management in Lake Rotorua: Using the N-Manager model, Motu working paper [draft obtained from Simon Anastasiadis].

Bryant, J.R. , G. Ogle, P.R. Marshall, C.B. Glassey, J.A.S. Lancaster, S.C. García, and C.W. Holmes. 2010. Description and evaluation of the Farmax Dairy Pro decision support model. *New Zealand Journal of Agricultural Research*, 53: 1, 13-28.

Carter, D. 2011. Budget 2011: Lifting investment in irrigation. Available online at http://www.beehive.govt.nz/release/budget-2011-lifting-investment-irrigation (Accessed 10 March 2012).

Clothier, B.E., S.R. Green and M. Deurer. 2008 Preferential flow and transport in soil: Progress and Prognosis. *European Journal of Soil Science* 59:2-13.

Hendy, J., S. Kerr, T. Baisden. 2006. Greenhouse gas emissions charges and credits on agricultural land: What can a model tell us? *Motu Working Paper 06-04*, Motu Economic and Public Policy Research, Wellington. Available online at http://motu-www.motu.org.nz/wpapers/06_04.pdf. (Accessed 10 March 2012)

IPCC. 2000. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.* Penman J, D Kruger, Galbally I, Hiraishi T, Nyenzi B, Emmanul S, Buendia L, Hoppaus R, Martinsen T, Meijer J, Miwa K, Tanabe K (Eds). IPCC National Greenhouse Gas Inventories Programme. Published for the IPCC by the Institute for Global Environmental Strategies: Japan.

Johansson, R., M. Peters, and R. House. 2007. *Regional Environment and Agriculture Programming Model*, TB-1916. U.S. Dept. of Agriculture, Econ. Res. Serv. March 2007.

Lincoln University. 2010. *Financial Budget Manual*. Ed. Jane Pangborn. Lincoln University Press: Canterbury.

Menneer, J.C., Ledgard, S.F. and A.G. Gillingham. 2004. Land use impacts on nitrogen and phosphorus loss and management options for intervention, report prepared for Environment Bay of Plenty. Available online at http://www.boprc.govt.nz/media/34344/TechReports-040601-LandUseImpactsNandPloss.pdf (Accessed 10 March 2012).

Ministry of Agriculture and Forestry (MAF). 2010a. Canterbury Farm Monitoring Reports. Available online at http://www.maf.govt.nz/news-resources/publications.aspx?title=farm%20monitoring%20report. (Accessed on 13 June 2011).

Ministry of Agriculture and Forestry (MAF). 2010b. Situation and Outlook for New Zealand Agriculture and Forestry. Wellington, New Zealand: MAF Policy Publication.

Monaghan, R. M., C. A. M. de Klein and R. W. Muirhead. 2008. Prioritisation of farm scale remediation efforts for reducing losses of nutrients and faecal indicator organisms to waterways: A case study of New Zealand dairy farming. *Journal of Environmental Management* 87(4): 609-622.

New Zealand Government. 2011. *National Policy Statement for Freshwater Management 2011*. Issued by notice in The Gazette on 12 May 2011. Available online at http://www.mfe.govt.nz/publications/rma/nps-freshwater-management-2011/index.html (Accessed on 15 June 2011).

New Zealand Land Resource Inventory (NZLRI). 2010. Available online at http://www.landcareresearch.co.nz/databases/nzlri.asp (Accessed on 1 November 2010).

New Zealand Ministry for the Environment (MfE). 2011. *New Zealand's Greenhouse Gas Inventory 1990–2009,* ME Report 1045.

OVERSEER. 2010. *OVERSEER® For on-farm management and decision support.* Available online at http://www.overseer.org.nz/ (Accessed on 15 December 2010).

Parfitt, R.L., H.J. Percival, R.A. Dahlgren and L.F. Hill. 1997. Soil and solution chemistry under pasture and radiata pine in New Zealand. *Plant and Soil* 191(2): 279-290.

Paul, T., M. Kimberley, P. Beets. 2008. Indicative Forest Sequestration Tables. Scion report prepared for Ministry of Agriculture and Forestry, P.O. Box 2525, Wellington.

Smith, N. 2011. Budget 2011: New fresh water clean-up fund. Available online at http://www.beehive.govt.nz/release/budget-2011-new-fresh-water-clean-fund (Accessed 15 June 2011).

Appendix A. Mathematical Representation of NZFARM

Variables

NR	net returns to agriculture and forestry production (million \$)
X	activity (ha)
L	available land (ha)
Q	land use change (ha)
Y	product output (kg, m^3)
W	irrigation water consumption (m^3)
E	environmental output (kg CO_2e, N, P)

Parameters

P	price (\$/kg, \$/m^3)
τ	environmental tax (\$/kg)
α^{proc}	processing coefficient (kg/ha, m^3/ha)
ω^{live}	livestock input cost (\$/ha)
ω^{vc}	variable input cost (\$/ha)
ω^{fc}	fixed input cost, annualised over 20 years (\$/ha)
ω^{land}	land use conversion cost
γ^{env}	environmental output coefficient (kg/ha)
γ^{water}	irrigation water input (m^3/ha)
L^{init}	initial land area (ha)
X^{init}	initial activity area (ha)

Indices

r	*region*
s	*soil*
l	*land use*
e	*enterprise*
m	*land management*

Objective Function

$$\text{Max } NR = \sum\nolimits_{r,s,l,e,m} \left\{ \begin{array}{c} pY_{r,s,l,e,m} \\ -X_{r,s,l,e,m}\left[\omega^{live}_{r,s,l,e,m} + \omega^{vc}_{r,s,l,e,m} + \omega^{fc}_{r,s,l,e,m} + \tau\gamma^{env}_{r,s,l,e,m}\right] \\ -\omega^{land}_{r,s,l} Q_{r,s,l} \end{array} \right\} \tag{A1}$$

Subject to:

Product Balance

$$Y_{r,s,l,e,m} \leq \alpha^{proc}_{r,s,l,e,m} X_{r,s,l,e,m} \tag{A2}$$

Land Use Balance

$$\sum\nolimits_{e,m} X_{r,s,l,e,m} \leq L_{r,s,l} \tag{A3}$$

$$L_{r,s,l} \leq L^{init}_{r,s,l} + Q_{r,s,l} \tag{A4}$$

$$Q_{r,s} \leq \sum\nolimits_{l,e,m}\left(X^{init}_{r,s,l,e,m} - X_{r,s,l,e,m}\right) \tag{A5}$$

$$L_{r,s,DOC} = L^{init}_{r,s,DOC} \tag{A6}$$

Irrigation Constraint

$\sum_{s,l,f,m} \gamma^{water}_{r,s,l,e,m} X_{r,s,l,e,m} \leq \ W_r$ (A7)

Environmental Constraint

$\sum_{s,l,f,m} \gamma^{env}_{r,s,l,e,m} X_{r,s,l,e,m} \leq \ E_r$ (A8)

Non-negativity Constraint

$Y, X, Q, L, W, E \geq 0$ (A9)

TABLES

Table 1. Key Components of NZ-FARM, Hurunui Catchment, Canterbury, New Zealand

Region	Soil Type	Land Type	Enterprise	Irrigation Scheme	Fertilizer Regime	Mitigation Option	Variable Cost	Fixed Cost	Product Output	Environmental Indicators	Product Inputs
Plains Foothills Hills	Lismore Balmorals Hatfield Templeton	Pasture Cropland Horticulture Forest Scrub Dept of Conservation	Dairy - 3 Cows per ha, wintered on farm Dairy - 3 Cows per ha, wintered off farm Dairy - 3.5 Cows per ha, wintered on farm Dairy - 3.5 Cows per ha, wintered off farm Dairy - 4 Cows per ha, wintered on farm Dairy - 4 Cows per ha, wintered off farm Deer Pigs Mix of Sheep and Beef Grazing 100% Sheep Grazing	Irrigated Land Dry Land	100% rec. all nutrients 80% rec. N, 100% rec. all other nutrients 60% rec. N, 100% rec. all other nutrients 50% rec. N, 100% rec. all other nutrients No N, 100% rec. all other nutrients 0% rec. Lime, 100% rec. all other nutrients No fertilizer applied	Forest Carbon Sequestration DCDs Feed Pads	Beef stock replacement costs Sheep Stock Replacement cost Deer Stock replacement cost Dairy Stock replacement cost Pig stock replacement cost Wages - permanent Wages - casual Animal Health Dairy shed breeding Electricity Cartage Fertiliser Fertiliser application Fuel Shearing	Property taxes Insurance Land prep Tree planting Forest harvest Cultivation Forest management fee Herbicide application Fungicide application Pruning Thinning Harvest costs Harvest preparation DCD Application Feed pad construction	Milk solids Dairy calves Lambs Mutton Wool Cull cows Heifers Steers Bulls Deer: hinds Deer: stags Deer: velvet Pigs Berryfruit Grapes Wheat Barley Logs for pulp and paper Logs for Timber Other Misc.	N leached (kg N) P lost (kg P) Methane from animals (kg CO2e) N2O emissions – direct excreta and effluent (kg CO2e) N2O emissions – indirect excreta and effluent (kg CO2e) CO2 emissions - N fertiliser (kg CO2e) CO2 emissions – Lime (kg CO2e) N_2O emissions – direct and indirect N from fertiliser (kg CO2e) CO2 emissions – fuel (kg CO2e) CO2 emissions - electricity use (kg CO2e) Annual Forest C Sequestration (kg CO2e)	Dairy calves purchased Lambs purchased Rams purchased Ewes purchased Cows purchased Heifers purchased Steers purchased Bulls purchased Pigs purchased Dry matter Electricity used Fertiliser used - Urea Fertiliser used - Super Fertiliser used - Lime Fertiliser used - other Nutrients used -N

Region	Soil Type	Land Type	Enterprise	Irrigation Scheme	Fertilizer Regime	Mitigation Option	Variable Cost	Fixed Cost	Product Output	Environmental Indicators	Product Inputs
			100% Cattle Grazing Grapes Berry Fruit Wheat Barley Pine Radiata Plantations				Seeds Imported Feed costs - hay & silage Imported feed costs - crops Imported feed costs - grazing Imported feed costs - other Water charges Depreciation on capital Roads for forest plantations				Nutrients used -P,K,S Nutrients used -Lime Nutrients used -Other Fuel used - Petrol Fuel used - Diesel Irrigation rate Irrigation type Irrigation-number of days Seed used Supplementary feed bought - hay & silage Supplementary feed bought - crops Grazing Supplementary feed bought - other Harvest length

Table 2. Baseline Enterprise Area for Hurunui/Waiau and Manawatu Catchments (k ha)

Hurunui/Waiau

Enterprise	Hurunui Hills	Hurunui Plains	Hurunui Foothills	Waiau Hills	Waiau Plains	Waiau Foothills	Total
Arable	0.0	5.3	0.0	0.0	4.8	0.0	10.2
Forest	0.0	12.2	5.9	0.1	9.0	0.4	27.7
Dairy	0.0	19.7	1.7	0.0	2.5	0.1	24.0
Sheep and Beef	28.7	35.3	56.1	24.0	42.6	56.8	243.6
Other Pasture	0.0	1.1	0.0	0.0	0.1	0.0	1.2
Scrubland	6.1	2.3	0.4	9.1	0.2	9.8	27.8
DOC/Natural	76.7	0.3	7.5	149.4	0.6	13.3	247.8
Total	111.6	76.1	71.6	182.6	60.0	80.4	582.2

Manawatu

Enterprise	Manawatu Flats	Manawatu Hills	Tararua Flats	Tararua Hills	Total
Arable	5.4	0.2	1.0	0.1	6.5
Forest	6.0	7.7	3.8	4.8	22.3
Dairy	58.2	6.6	49.4	5.3	119.5
Sheep and Beef	68.7	75.0	38.4	132.5	314.6
Other Pasture	2.9	2.6	0.0	0.4	5.9
Scrubland	1.1	47.1	0.1	14.1	62.4
DOC/Natural	1.4	35.9	1.5	5.4	44.3
Total	143.6	175.1	94.3	162.6	575.5

Table 3. Baseline regional production output for Hurunui/Waiau and Manawatu Catchments (tons or k m^3)*

Hurunui/Waiau

Output	Hurunui Hills	Hurunui Plains	Hurunui Foothills	Waiau Hills	Waiau Plains	Waiau Foothills	Total
Milk Solids	0.0	23596.0	1620.9	0.0	2877.0	128.6	28222.4
Dairy Calves	0.0	1543.1	122.0	0.0	179.7	10.4	1855.1
Lambs	711.6	3139.4	3493.8	595.0	3605.9	3511.9	15057.6
Mutton	100.6	354.9	493.9	84.1	390.2	496.6	1920.3
Wool	107.8	644.7	529.2	90.1	723.6	532.1	2627.6
Cows	201.3	3375.5	735.2	168.3	393.1	499.5	5372.8
Heifers	1841.9	964.4	4362.8	1540.1	112.3	4370.0	13191.5
Steers	2048.5	7716.7	4769.5	1712.9	10158.8	4853.1	31259.4
Bulls	0.0	1.2	0.1	0.0	0.2	0.0	1.5
Deer Hinds	0.0	228.3	0.4	0.0	38.2	0.3	267.3
Deer Stags	0.0	151.0	0.4	0.0	25.3	0.3	177.1
Velvet	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pigs	0.0	2484.9	16.9	0.0	2.3	28.5	2532.6
Berryfruit	0.0	21.5	0.0	0.0	8.4	0.0	29.9
Grapes	0.0	19.1	34.0	0.0	2.2	53.4	108.8
Wheat	0.0	35799.1	0.0	0.0	36412.4	0.0	72211.4
Barley	0.0	8336.0	0.0	0.0	4141.6	0.0	12477.6
Pulp Logs	0.0	53.6	27.0	0.4	44.8	1.6	127.5
Timber	0.1	214.3	108.2	1.6	179.4	6.5	510.1

Manawatu

Output	Manawatu Flats	Manawatu Hills	Tararua Flats	Tararua Hills	Total
Milk Solids	58963.2	6747.7	46792.4	5003.2	117506.4
Dairy Calves	3097.1	355.8	2635.7	283.6	6372.1
Lambs	26736.2	6771.1	16730.5	11917.6	62155.3
Mutton	4132.3	2250.0	2620.5	3960.5	12963.2
Wool	2259.5	2742.2	1211.6	4826.7	11040.0
Cows	7406.1	1473.1	6302.7	1773.7	16955.7
Heifers	0.0	859.6	0.0	1513.0	2372.5
Steers	14450.7	2074.4	8211.4	3650.5	28387.0
Deer Hinds	284.8	267.3	3.5	38.3	593.9
Deer Stags	379.8	356.4	4.7	51.0	791.9
Velvet	8.4	7.9	0.1	1.1	17.6
Wheat	4887.8	0.0	638.2	0.0	5526.0
Barley	8713.5	298.5	3696.5	0.0	12708.5
Maize - Silage	24612.7	958.2	1073.4	925.3	27569.7
Maize - Grain	12070.1	476.8	80.9	463.1	13090.9
Potatoes	64632.1	1575.8	14463.7	0.0	80671.6
Pulp Logs	39.0	61.5	26.9	33.5	160.9
Timber	118.8	185.3	82.7	101.5	488.3

*Agriculture products in tonnes, while forest products are in thousand m^3

Table 4. Baseline GHG Emissions for Hurunui/Waiau and Manawatu Catchments (tCO_2e)

Hurunui/Waiau

GHG Category	Hurunui Hills	Hurunui Plains	Hurunui Foothills	Waiau Hills	Waiau Plains	Waiau Foothills	Total
CH4 Enteric Fermentation	40988	335471	206945	34285	304502	203008	1125199
CH4 Manure Management	187	7886	2704	157	3927	2423	17284
N2O Animal Waste Mgmt	0	323	11	0	16	1	351
N2O Grazing	12325	102104	62338	10371	88656	61358	337152
N2O Fertilizer	0	22019	1035	0	6888	63	30005
CO2 Fuel	153	8321	1066	128	5571	826	16064
CO2 Electricity	24	3763	334	20	1103	180	5422
Forest C Sequestration	-177757	-9596	-16662	-335094	-2202	-65682	-606993
Total Emissions	53676	479887	274433	44960	410663	267860	1531478
Net Emissions	-124081	470291	257771	-290134	408461	202177	924485

Manawatu

GHG Category	Manawatu Flats	Manawatu Hills	Tararua Flats	Tararua Hills	Total
CH4 Enteric Fermentation	751797	403834	486188	653592	2295411
CH4 Manure Management	16844	5478	12610	8163	43094
N2O Animal Waste Mgmt	442	50	374	40	906
N2O Grazing	203148	123876	127880	200230	655135
N2O Fertilizer	50751	7963	38965	9393	107072
CO2 Fuel	15994	3236	12248	3755	35232
CO2 Electricity	9085	1371	7205	1429	19090
Forest C Sequestration	-197921	-483189	-137088	-199937	-1018135
Total Emissions	1048059	545808	685470	876602	3155940
Net Emissions	850138	62620	548383	676665	2137805

Table 5. Change in Key Outputs from Baseline for Environmental Policy Scenarios

Policy Scenario	**Net Revenue**	**Total GHG Emissions**	**N Leaching**	**P Leaching**
		Hurunui/Waiau		
AgETS	-13%	-26%	-11%	-6%
Nutrient	-5%	-22%	-20%	-20%
AgETS_NUT	-15%	-34%	-20%	-20%
		Manawatu		
AgETS	-20%	-40%	55%	-38%
Nutrient	-1%	-16%	-20%	-20%
AgETS_NUT	-21%	-32%	-20%	-29%

Figure 1. Structure of inputs and outputs in NZ-FARM

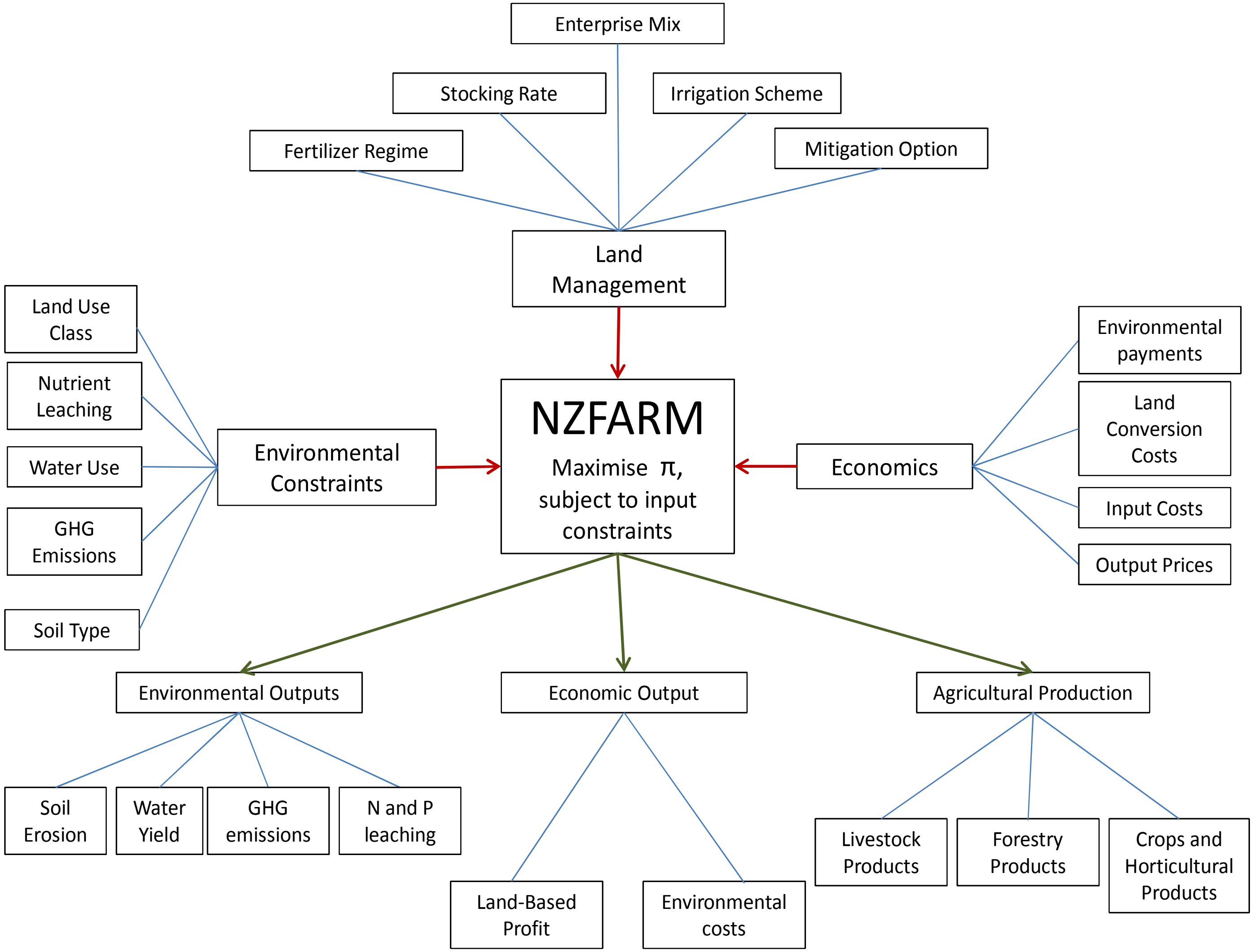

Figure 2. Structure of CET Function Nest in NZ-FARM

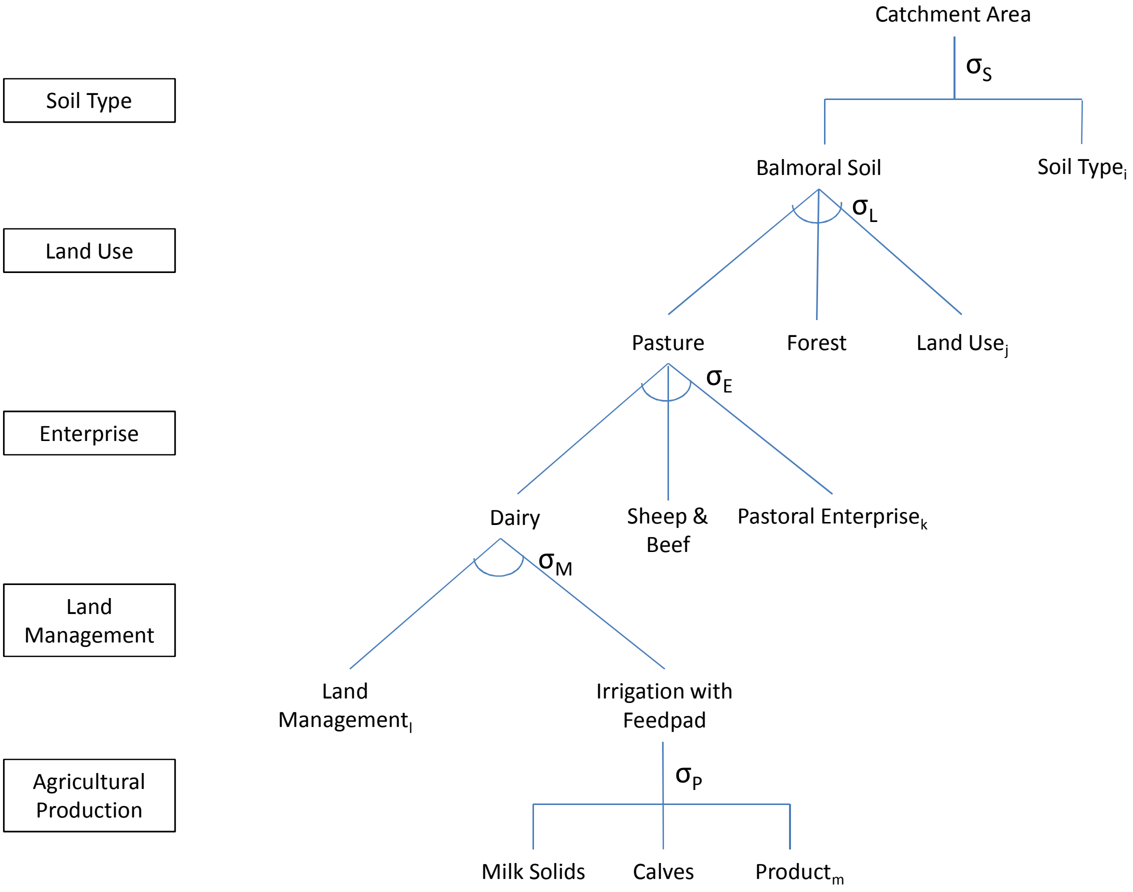

Figure 3a. Hurunui and Waiau Catchments, South Island, New Zealand

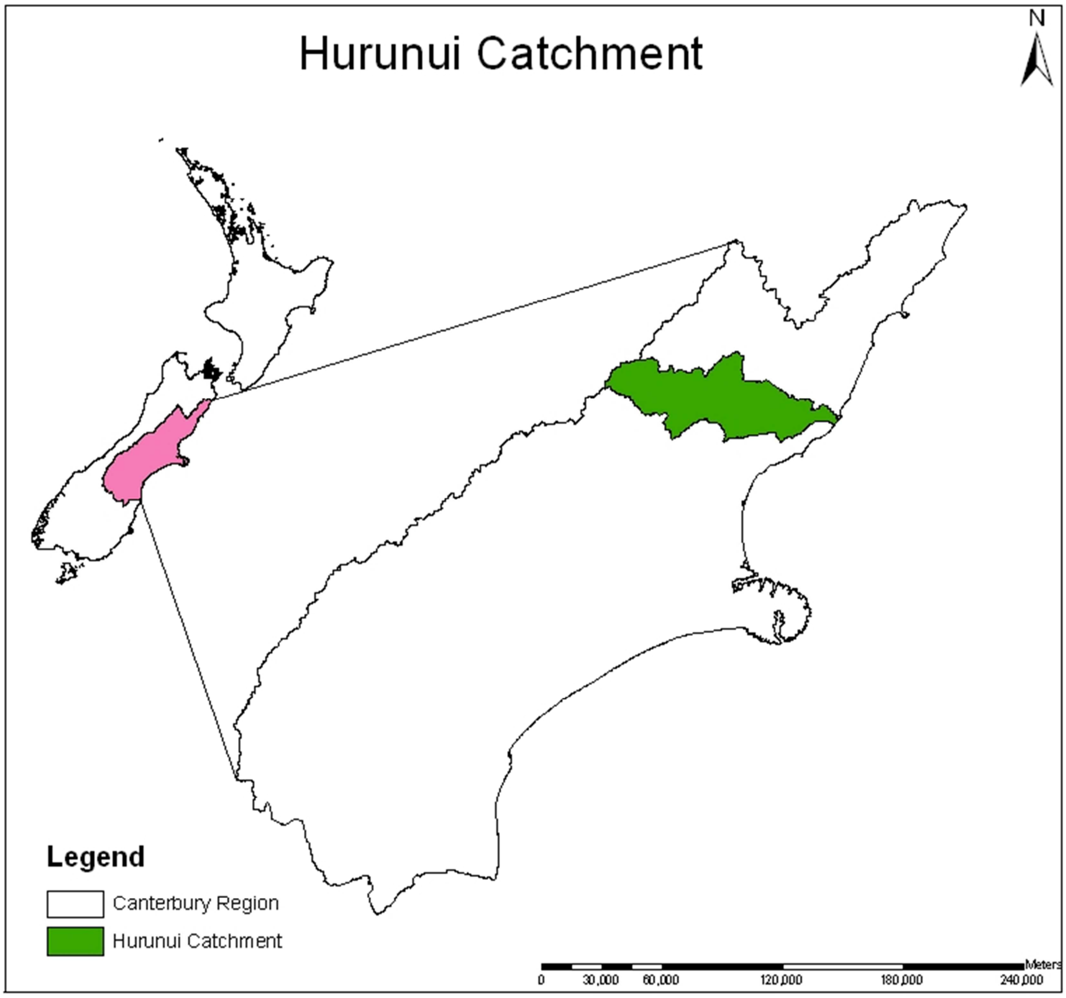

Figure 3b. Manawatu Catchment, North Island, New Zealand

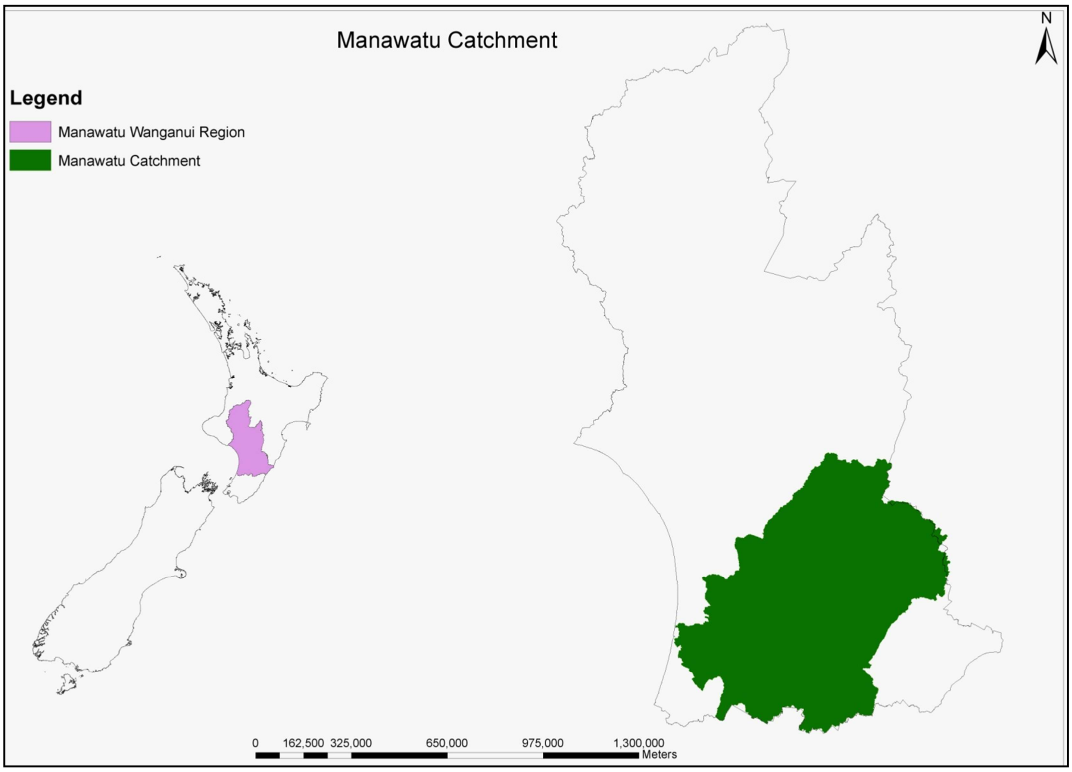

Figure 4a. Baseline Enterprises for Hurunui/Waiau Catchment

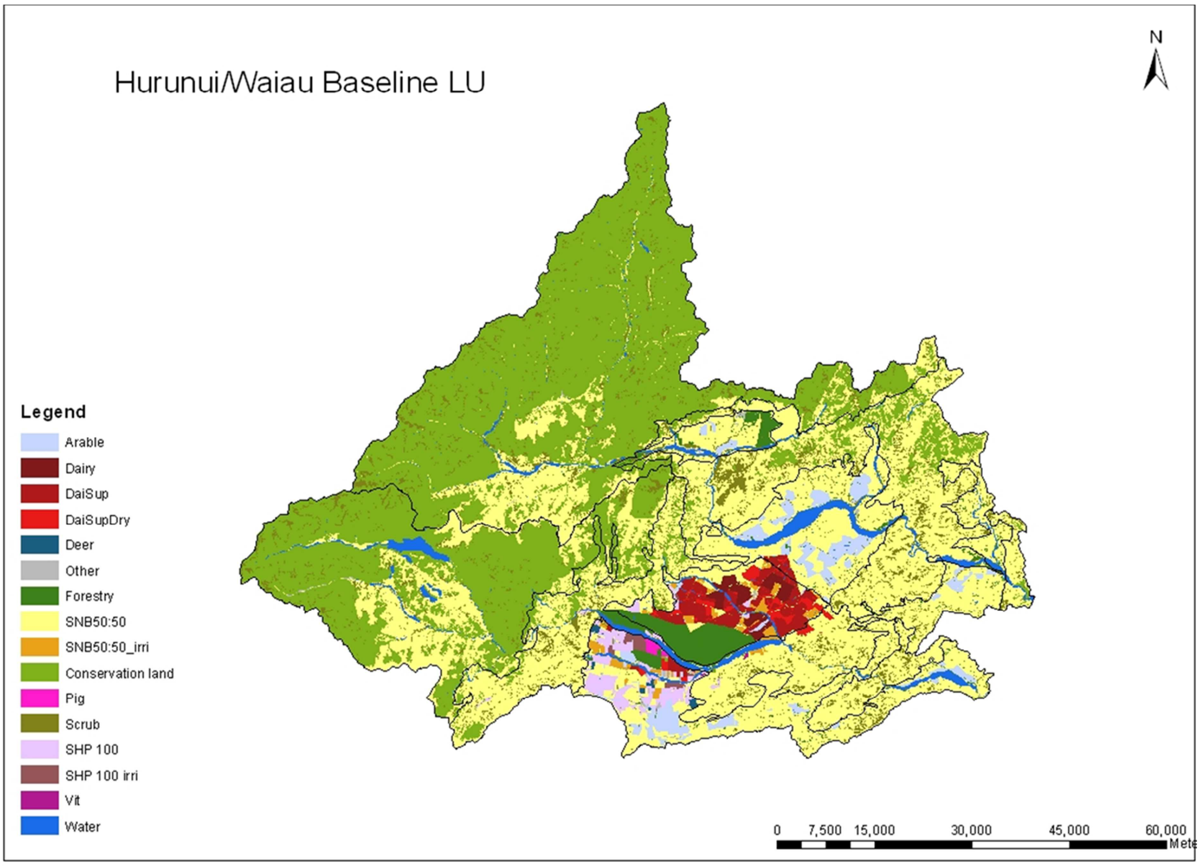

Figure 4b. Baseline Enterprises for Manawatu Catchment

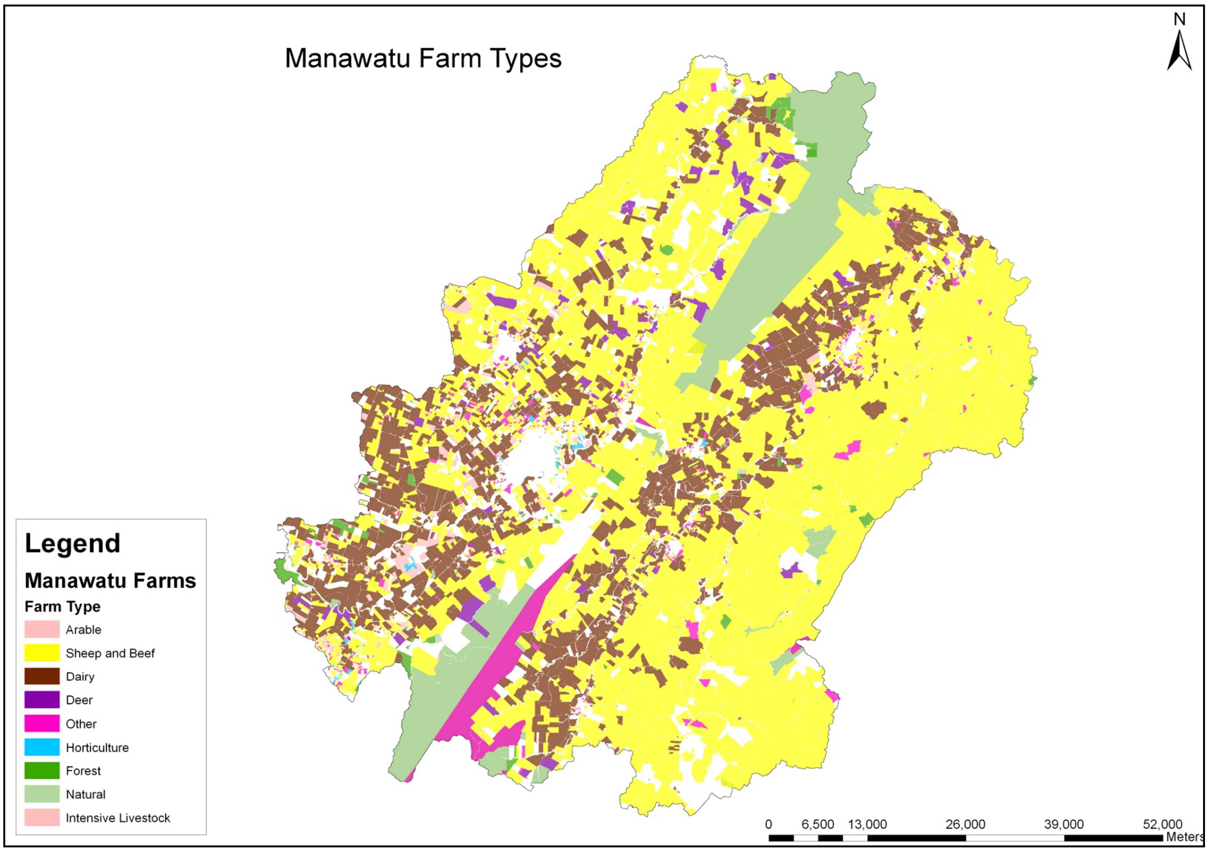

Figure 5. Aggregate Percentage Change in Enterprise Area for Policy Scenarios

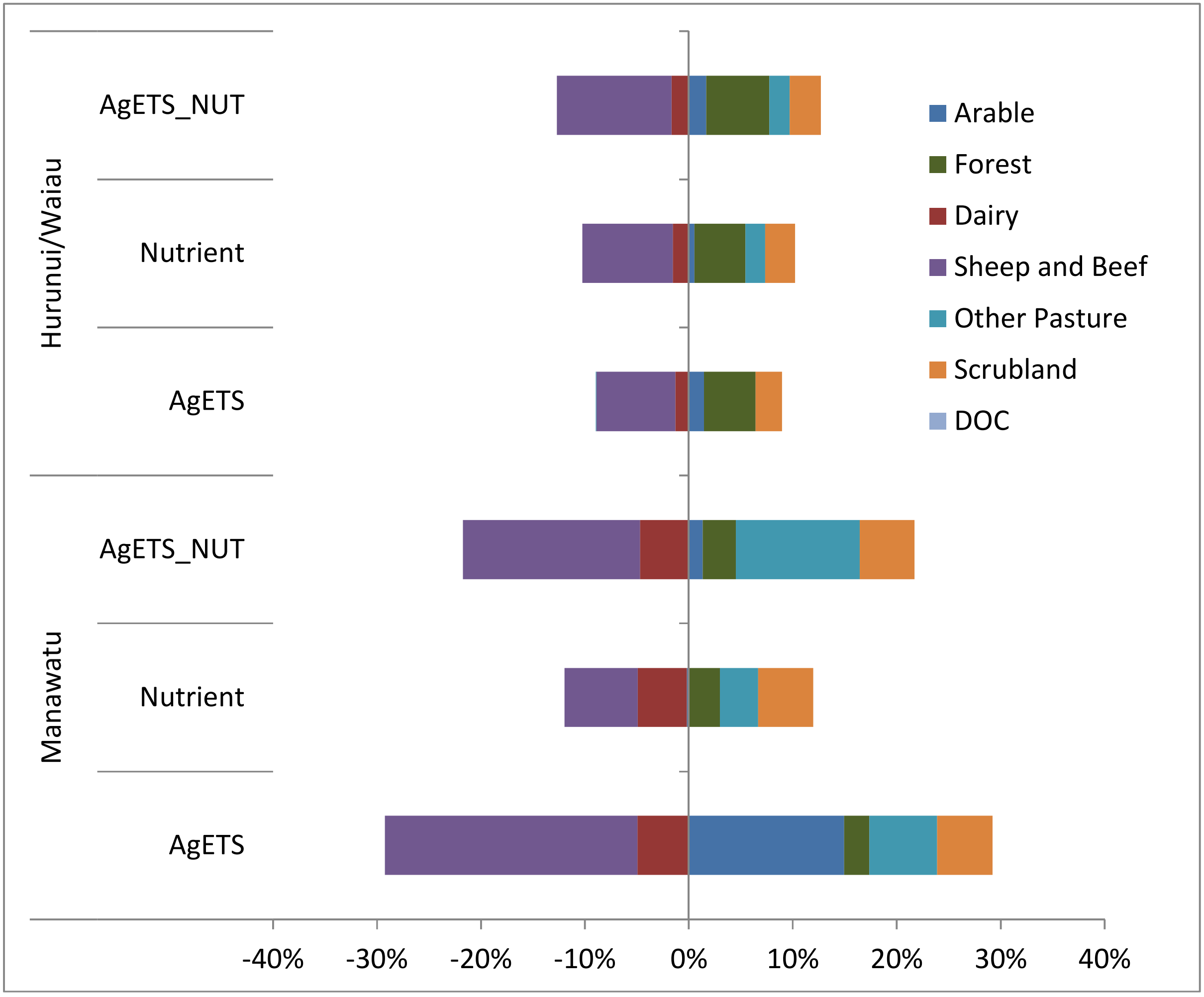

Figure 6. Detailed GHG Emissions for Baseline and Policy Scenarios