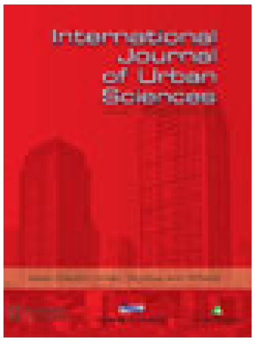


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# Economic and land use impacts of net zero-emission target in New Zealand

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**ABSTRACT**

In this study, we examine the economic impacts of net zero-emission target in New Zealand, applying an integrated forest-computable general equilibrium model. The model is set to simulate equilibrium carbon permit price and sectoral output levels given the emission trading market, which is also endogenously determined within the model. When the agricultural sector is subject to a legally binding target, an equilibrium carbon permit price is estimated to be NZ$85/t$CO_2$e (US$60/t$CO_2$e) and this results in a 1.4% loss of gross domestic product from the baseline level and a 22% reduction of greenhouse gas emissions. Exclusion of the agricultural sector, however, would reduce the permit price to NZ$68/t$CO_2$e (US$48/t$CO_2$e) and lead to a 1.2% loss of gross domestic product and a 5% emissions reduction. This result suggests that the inclusion of the agriculture sector in the emissions trading scheme requires costs for policy compliance but can be cost-effective. It drives up compliance costs by 17%, but leads to 4.4 times the absolute emissions reduction expected when the agriculture sector is excluded.

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**KEYWORDS**
CGE modelling; carbon emission units; land use; carbon dioxide emissions mechanism; zero carbon act; New Zealand

**JEL Classification**
Q23; Q24; Q54; Q68

## Highlights

- New Zealand implements a domestic Emissions Trading Scheme and sets a vision of net-zero emissions in 2050
- We used an integrated forest-computable general equilibrium model to study New Zealand's carbon trading market
- The equilibrium carbon permit price is estimated to be NZ$68-85/t$CO_2$e (US$48-60/t$CO_2$e) depending on the inclusion of agricultural sectors
- Inclusion of the agricultural sector leads to 4.4 times the absolute emissions reduction and can be cost-effective

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This article has been republished with minor changes. These changes do not impact the academic content of the article.

## 1. Introduction

New Zealand (NZ) may be far from being a major greenhouse gas (GHG) emitter in absolute terms, but it is in per capita terms. In 2017, for example, this small open economy ranked fifth out of the 35 member countries in the Organization for Economic Co-operation and Development in terms of emissions per person (OECD, 2017). In this context, the NZ government has increased policy emphasis on the transition toward a low-carbon economy, coming up with the Zero Carbon Amendment Bill that passes into law 'Climate Change Response (Zero Carbon) Amendment Act 2019' (the act) at late 2019. This act commits to making efforts to limit the global average temperature increase to 1.5 °C above pre-industrial levels and also sets an ambitious national GHG reduction target, in which the NZ economy will achieve net-zero emissions by 2050. Here, net-zero emission indicates that economy-wide carbon sequestration capacity through tree planting and pro-forestry land use changes more than offsets total anthropogenic GHG emissions. The scope of GHGs that will be covered by the act includes all types but biogenic methane. However, the GHG reduction target requires to 'reduce emissions of biogenic methane within the range of 24–47% below 2017 levels by 2050 including to 10% below 2017 levels by 2030' (Ministry for the Environment, 2019a 2019b). Net-zero emission targets will be met primarily through an extensive operation of the existing emission trading scheme (ETS) launched in 2008.

The NZ ETS (NZETS) is among the world's earliest market-based emission trading systems operated at a national level (ICAP, 2019). The scheme covers six gases, namely, carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), sulfur hexafluoride, hydrofluorocarbons, and perfluorocarbons. In terms of industrial sectors, the scheme initially focused solely on the forestry sector but has gradually extended to include stationary energy, industrial processing, and liquid fossil fuels in 2010 and waste and synthetic GHG sectors in 2013. The critical issue in implementing NZETS in connection with the zero-carbon act is the inclusion of the agricultural sector in the scheme. At present, the agricultural sector is excluded from NZETS, although $CH_4$ and $N_2O$ emissions from this sector account for approximately half of the local anthropogenic GHG emissions. Accordingly, the inclusion of the agricultural sector in NZETS, combined with a net-zero emission target, can cause a substantial shock to the economy.

The impact analysis of the extended NZETS seems necessary, but existing studies pay minimal attention to this plausible scenario or leave substantial room for further improvement. Notably, the agricultural sector, accounting for nearly half of NZ's national GHG emissions, has long been excluded from the local policy because its inclusion in NZETS lacks technical feasibility. However, increased sectoral coverage, inclusive of the agricultural sector, is highly plausible given the ambitious mitigation goals proposed in the zero-net emission act. Attention to this scenario gains policy ground.

Existing NZETS impact studies that adopted computable general equilibrium (CGE) approaches are subject to limitations in two aspects (Table 1). The first is the adoption of exogenous carbon prices, which is prevalent in the literature (see NZIER, 2008, 2018; Stroombergen, 2007), with few exceptions in recent studies (see Daigneault, Greenhalgh, & Samarasinghe, 2018; Diukanova, Andrew, & Lennox, 2008). However, an

**Table 1.** CGE Studies on NZETS.

| | *Years Analyzed* | *Model Class* | *ETS Coverage* | *Carbon Sequestration* | *Carbon Price* |
|---|---|---|---|---|---|
| Diukanova and Andrew (2008) | 2008 | Static CGE | All the ETS sectors and agriculture, no cap-and-trade, captures $CO_2e$ that involves $CO_2$, $N_2O$ and $CH_4$ emissions | N/A | Endogenous |
| Fernandez and Daigneault (2015) | 2007–2045 | Dynamic CGE | Primary sectors, manufacturing and value-added sectors, and energy sectors, global cap-and-trade, captures $CO_2$ and non-$CO_2$ GHGs that include $CH_4$, $N_2O$ and 14 fluorinated gases | Exogenous | Endogenous |
| NZIER (2008) | 2012, 2015, 2025 | Static CGE | All the economic sectors and agriculture, no cap-and-trade, captures $CO_2e$ that involves $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, and $SF_6$ | Exogenous | Exogenous |
| NZIER (2018) | 2017–2050 | Dynamic CGE | All the economic sectors and agriculture, no cap-and-trade, measures $CO_2e$ | Exogenous | Endogenous |

Note: This table limits to NZETS by CGE study only. No studies mentioned above attempt a model linkage. That is, no special focus made on forest carbon sequestration within their models.

ETS is a market-based control over the quantity of emissions rather than their price, and the carbon permit price is a function of market demand for emissions and the supply of carbon permits. Accordingly, an endogenous carbon-pricing structure is essential for a realistic CGE analysis. The second limitation is the weak linkage of a carbon-pricing structure to the forestry stock. Not many studies focus on such linkage, but Fernandez and Daigneault (2015, 2018) used 'soft-link' approach to integrate a global timber model to a CGE framework, assessed the economic costs for NZ responding to its Paris Agreement. Our approach used a similar linkage structure but with a simpler method and specific to NZ timber species that covered dominantly by the ETS.

Achieving net-zero emissions under the Act indicates that the national carbon sink capacity is equal to or exceeds anthropogenic emissions. Hence, modelling the explicit linkage between GHG emissions and forestry stock is required to ensure that the quantity of the former is determined by the latter.

In recognition of the gap found in the literature, we examine the potential impact of the zero-carbon act on NZ's economy with an improved CGE framework. In particular, our study has two primary research questions: (i) What are the optimal carbon permit price and economy-wide policy compliance cost required to meet the proposed net-zero emission targets; and (ii) How can the inclusion of the agricultural sector in NZETS affect such carbon price and compliance cost? We apply a CGE model that links with a partial equilibrium forest model and land use accounts. Our model called the forestry–CGE (F–CGE) model, attempts to overcome the prevalent methodological limitations such that the endogenous carbon-pricing structure directly interacts with emission caps.

The rest of this paper is organized as follows. Section 2 offers an overview of NZ's current mitigation policies. Section 3 describes our method, with emphasis on the key structure in our F–CGE model. Section 4 reports our central results and findings. Section 5 concludes with the synthesis of our findings, and key policy implications are drawn from such synthesis.

## 2. Literature review

NZ's mitigation effort traces back to as early as the late 1990s when it signed the Kyoto Protocol. Under the Kyoto Protocol, the NZ government committed to maintaining its GHG emissions to the 1990 levels, with an annual reporting responsibility. NZ completed its Protocol ratification procedure by late 2002 and implemented mitigation measures while reporting its annual national GHG inventory to the United Nations Framework C onvention on Climate Change during the first commitment period (2008–2012). In late 2015, NZ ratified the Doha Amendment to the Kyoto Protocol and continued its participation in the global mitigation effort during the second commitment period (2013–2020) (Ministry for the Environment, 2018).

The enactment of several key regulations precedes the implementation of NZETS. Among these regulations are environmental policy frameworks and climate legislation, such as the Environment 2010 Strategy, the Resource Management Act (RMA), and the Climate Change Response Act 2002. The Environment 2010 Strategy was adopted in 1995 but eventually lost its momentum because of two major reasons: one is the lack of clear national policy guidance in the form of national environmental standards, and the other is the absence of effective economic instruments to quantify the environmental cost, which consequently reduces regulatory efficiency (Kelly, 2010; OECD, 2007). By contrast, RMA and the Climate Change Response Act 2002 have remained as primary legislation for climate policies with multiple amendments. RMA intends not only to regulate pollution-intensive sectors but also to promote the market penetration of renewable energy. The Climate Change Response Act 2002 is important because it offers legal foundations for NZETS as a primary policy instrument to meet its international commitment under the Kyoto Protocol.

In 2008, NZETS was officially launched with a one-way linkage to the international carbon market covered by the Kyoto Protocol. A year earlier, the fourth NZ national government considered carbon tax as a primary mitigation measure before NZETS, but the fifth labour government eventually chose the latter over the former given the strong public preference for ETS. Under the system, NZ firms can initially exchange domestic permits denominated in NZ units with permits adopting Kyoto units when the latter has higher prices (Ormsby & Kerr, 2016). In this regard, the system differs from when two competitive markets are a full linkage of two competitive markets; wherein a single, unique market price exists for traded carbon permits. In 2015, however, this one-way linkage was eliminated. Since then, NZETS has remained as a domestic system with independent allowance supply and pricing mechanisms.

The primary function of this domestic ETS was to set a market-based carbon price to limit national GHG emissions below the benchmark level. NZETS initially intended to cover all economic sectors but eventually excluded the agricultural sector due to a technical challenge in reducing biological emissions (Table 2). Instead of being regulated by NZETS, agricultural producers are only obliged to report their biological emissions to the government on an annual basis. Another aspect that distinguishes NZETS from other ETS models, such as those of the European Union and China, is the non-existence of a hard emission cap at the local level. That is, NZETS does not impose its explicit emission caps because it operates as a part of the Kyoto Protocol with a globe-wide emission cap. As a small open economy with limited global market impact, NZ

**Table 2.** Sector aggregation.

| Sector | Sector specification | ANZSIC code* |
|---|---|---|
| Agriculture | Horticulture and fruit growing | A01 |
| | Sheep–beef cattle and grain farming | A01 |
| | Dairy cattle farming | A01 |
| | Other agriculture | A01 |
| Forestry | Forestry | A03 |
| Energy | Stationary energy | B06-10, C17, D26 |
| | Synthetic gases | D26 |
| | Nonrenewable electricity | D26 |
| | Renewable electricity | D26 |
| Manufacture | Timber processing | A03, C14, C25 |
| | Agriculture product processing | C11 |
| | Other manufacturing | C12, C13, C15, C16, C19, C23, C24 |
| | Industrial processes | C18, C20, C21, C22 |
| Others | Waste | D29 |
| | Retail and wholesale trade | G39-43 |
| | Service | H4-S96 |

Note: * is the ANZSIC 06 code, and we keep 2 digits for the sector classification.

adopts a global carbon price, instead of pricing carbon locally (Ministry for the Environment, 2007).

The NZ government recently came up with an ambitious net-zero emission goal and set a timeline by 2050 under the commitment to the Paris Agreement. This goal concretizes NZ's vision to build a climate-resilient society and extends the pre-existing 30% carbon-reduction goal for 2030, compared with the 2005 emission levels (Ministry for the Environment, 2018). In the statement, 'net-zero emissions' implies that natural sequestration capacity completely offsets or exceeds gross anthropogenic GHG emissions other than biogenic methane ($CH_4$) from all economic activities. Achieving this goal requires an extension of the existing NZETS and the potential introduction of additional mitigation measures.

Among the central aspects that have attracted considerable public attention is the extension of NZETS' sectoral coverage. In particular, whether biological emissions from agriculture ($CH_4$ and $N_2O$), accounting for approximately half of the national GHG emissions, should also be regulated as part of NZETS has been a topic of serious discussion. At present, agricultural producers are excluded from the mandatory NZETS participant list, but they are advised to report annual farm-level emissions voluntarily. Given the position of the agricultural sector as the largest sectoral emitter, achieving the ambitious goal of net-zero emissions may be infeasible without extending the scope and stringency of the current NZETS. Consequently, the NZ government announced the pricing of agricultural emissions in effect from 2025. Regulating agricultural emissions initially aims at a 10% biogenic methane reduction by 2030 from the 2017 levels, but the goal will be further extended to a 24%–47% reduction by 2050 (Ministry for the Environment, 2019). Our study considers the significant effect of methane emissions from agricultural activities; thus we embedded methane emissions into our dataset.

Apart from the agriculture sector, emissions from deforestation account for almost one-fourth of the anthropogenic emissions globally (Bustamante et al., 2014). By contrast, approximately one-third of the emissions are removed by forestry (Griscom et al., 2017). Considering the contribution of forestry in alleviating the issue of climate change and limiting the rise of global average temperature, the planting-related activities shall be encouraged. For instance, creating forest park at city level (Oh & Jeong, 2020; Ziari, Pourahmad, Mehrabani, & Hosseini, 2018). Besides, studies focus on investigating the effect of accounting for forestry carbon sequestration have approved the significance of involving forestry in carbon mitigation policy (Bosetti, Lubowski, Golub, & Markandya, 2011; Daigneault et al., 2017; Favero, Mendelsohn, & Sohngen, 2015; Fernandez & Daigneault, 2016, 2018; Grassi et al., 2017; Turner, 2018). However, a lower price of carbon permit would reduce forester's motivation to afforestation or extending the harvested period, which in turn lowers the efficiency of the ETS. The NZETS involves forestry since the initial step of designing the mechanism which contributed largely to the national mitigation efforts. The primary emission source released from forestry relates to the land-use conversion. Compared with agricultural land, forest land has the most significant carbon density (Feng et al., 2020). Thus, transferring land type from forestry to agriculture or other use can lead to a carbon stock loss. The economic activities, land-use change, and carbon emissions linked interactively (Chuai et al., 2015). Managing forestry helps to abate the emission level and then create environmental and social benefits (Waheed, Chang, Sarwar, & Chen, 2018). For example, the social emission abatement cost can be reduced through afforestation and a well-established carbon trading market (Lin & Ge, 2019).

## 3. F–CGE model

As discussed earlier, we develop and apply the F–CGE model to examine the potential impact of the zero-carbon act on NZ's economy. An innovative feature of the model lies in its attempt to link up conventional economic accounts with carbon stock and land use changes. In this structure, carbon sequestration capacity, demand for carbon permits, and carbon permit price are endogenously determined within the model under a joint optimization structure. We elucidate the model's structure in this section.

### 3.1. Model structure

The F–CGE model developed in this study is a static model of NZ's economy that consists of 16 production sectors and 15 commodities (Figure 1 and Table 2). The social accounting matrix (SAM) for the model is built on NZ's 2007 supply–use input–output table (StatsNZ, 2007), and each production sector is linked up with satellite physical accounts, such as GHG emissions, renewable energy, and land use accounts. Considering data availability, the baseline datasets for the satellite accounts are constructed for 2016 from various secondary sources, including the Ministry for the Environment (2018) and StatsNZ (2007). For the linkage between economic and physical accounts, the baseline SAM is scaled up by applying a constant adjustment factor, and the F–CGE model is calibrated to reproduce the 2016 level of the gross domestic product (GDP) under the business-as-usual (BAU) scenario.

Within the model structure, land use patterns are primarily determined by sectoral output levels and the elasticity of substitution for each land type. Changes in the sectoral output levels can affect land use patterns through two channels. On the one hand, output growth in a particular sector requires greater land input, and thus, drives up demand for a type of land attached to that sector. On the other hand, increased output means

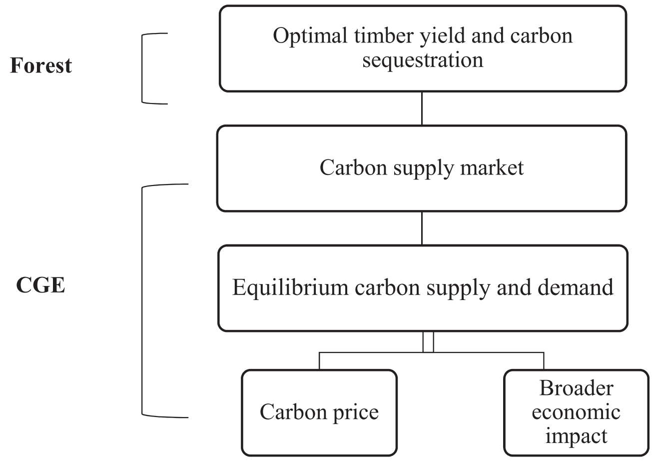


**Figure 1.** Analytic framework.

increased emissions, and a high demand for carbon permits can lead to a pro-forest land use conversion. The other key driver is substitution elasticity. The elasticity for forest is lower than that for other types of land, and an inelastic supply makes forest more expensive than agricultural land. This relative price can affect land use patterns.

In essence, the F–CGE model implements a nested production structure with constant elasticity substitution (CES) functions at each stage (Figure 2). F–CGE integrates a partial equilibrium forest growth sub-model (or module) into a general equilibrium framework. The forest growth module applies a partial equilibrium structure, wherein a calibrated optimal rotation age determines the carbon sequestration capacity for a stock of trees, measured per hectare. In the integrated model (i.e. F–CGE), the original carbon sequestration capacity, estimated by the forest growth module, is adjusted endogenously to ensure conventional closure rules for general equilibrium, such as market clearance, zero profit, and income balance; this procedure considers the interactions of the carbon market with other commodity and factor markets (Burfisher, 2011).

With regard to production output, each sector requires not only conventional inputs, such as intermediate goods and services (INT) and factor inputs (VAL), but also carbon permits to comply with a given GHG regulation. Here, the quantity of carbon permits

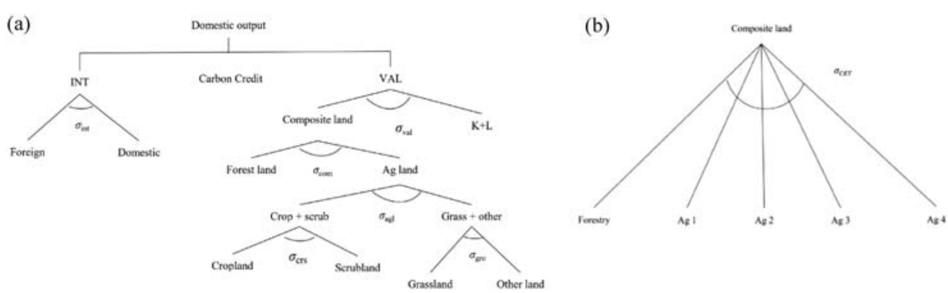


**Figure 2.** Structure of Forest-CGE: (a) Nesting structure for the production sector; (b) Land allocation among sectors.

required for production is determined by sector-specific carbon intensity and sectoral output levels. The INT bundles are subject to the Leontief, a special case of CES function with a substitution elasticity (notated with $\sigma$) of zero, and posit no substitution across different production sectors. Domestic and foreign commodities within each sector are differentiated from each other and regarded as imperfect substitutes, applying the Armington elasticity (Armington, 1969). Domestic goods are transformed into exported goods in accordance with a constant elasticity of the transformation function. That is, elasticity determines how easily domestic commodities can be sold overseas. Similarly, it reflects the substitution between imported goods and domestic commodities. Elasticities for other bundles, including the VAL nest that consists of labour, capital, and composite land, are also nonzero and drawn from the literature.

Land is modelled as a production factor, and five land types, namely, forest, grass, crop, scrub, and others, are considered in combination with five primary subsectors, namely, forestry, horticulture, sheep–beef, dairy farming, and other agricultural production. Each type of land is intensively used by one of the five primary subsectors, and thus, the land composite mix is determined by the latter's output level. Land use conversion among the five land types may occur to meet demands and the substitution elasticities applied to the composite land bundle reflect relative politico-economic costs and technical challenges. The elasticity estimates used in this study are drawn from the relevant empirical literature (Golub, Hertel, & Sohngen, 2009; Rae & Strutt, 2011; Rutherford, 2003). The physical endowments for each land type are obtained by merging geographic data (LCDB V2) and industrial use data provided by Agribase (AsureQuality, 2013; LRIS, 2002).

### *3.2. Data and scenario setup for analysis*

The model includes all six GHG species that are currently covered by NZETS. Carbon permit price is defined on a standard $CO_2$ equivalent ($CO_2e$) measurement unit, wherein global warming potential is applied to non-$CO_2$ GHGs for conversion. In the model, the forestry sector functions as the sole permit supplier, and the quantity of permits that can be issued is capped at the sector's aggregate sequestration capacity. Trading carbon permits is allowed only among domestic producers, enforcing emission trading to operate in a closed market. All production sectors that are currently covered by NZETS, i.e. forestry, industrial processes, synthetic gases, waste, liquid fossils fuels, and stationary energy, are subject to GHG regulations and participate in emission trading.

We choose 2016 as the benchmark year, because this is the year when the latest national GHG inventory report was published at the time of our analysis. As of 2016, total anthropogenic GHG emissions in NZ were 78.7 $MtCO_2e$, and 49.2% of the emissions or 38.7 $MtCO_2e$ were from the agriculture sectors. We estimate horticultural emissions from direct and indirect nitrogen losses from agricultural soils and the use of nitrogenous fertilizers due to limited data regarding these emissions. In this study, we focus on two dominant tree species in NZ (radiata pine and Douglas fir) subject to the tree-planting regulations of NZETS across the 12 domestic regions (Figure 3).[1] Timber yield data are constructed from the Ministry for Primary Industries (2011).

Imposing emission caps on par with aggregate carbon sequestration capacity requires a coupling between physical and economic accounts under an integrated optimization

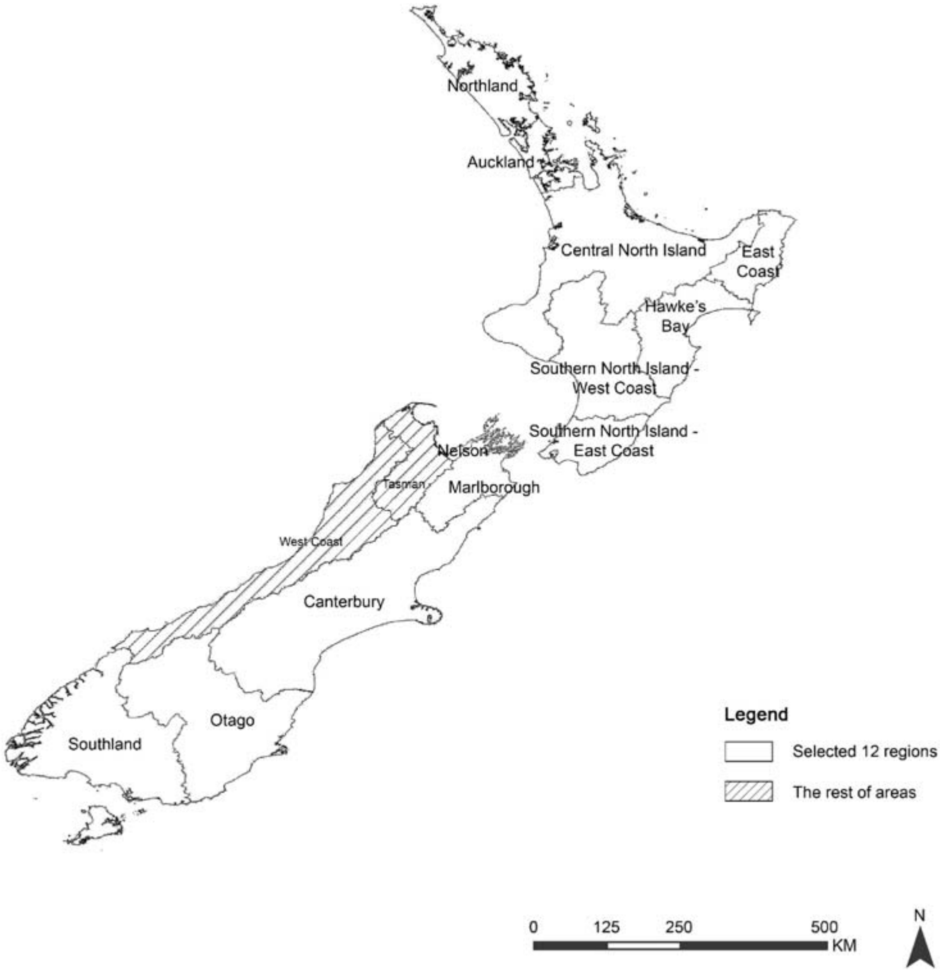


**Figure 3.** Map of New Zealand.

structure. Forest owners are liable for carbon emissions when trees are harvested, given that carbon permits are issued on the security of forests (as carbon sinks). Associated decisions, e.g. maintaining a forest for carbon permits or cutting trees for timber production, will be made after the value of timber products is compared with the value of a forest as a carbon sink. Accordingly, forest owners are modelled to maximize profit in terms of the net present value (NPV) of the forest stock, subject to timber sales, carbon sequestration, and carbon emission liability payment (Kooten, Binkley, & Delcourt, 1995; Sands & Kim, 2008).

Our impact analysis is based on the comparison of the model simulation results under the BAU scenario, which is not constrained by net-zero emission requirements, with those under two counterfactual scenarios that comply with net-zero emission conditionality. The first counterfactual scenario, denoted as S1, assumes that NZETS covers the agriculture sector and all carbon permits are sourced from forestry. The other scenario is S2, which is similar to S1, but excludes the agricultural sector from NZETS (Table 3).

**Table 3.** Scenarios.

| | BAU | S1 | S2 |
|---|---|---|---|
| ETS | O | O | O |
| Agriculture involved | X | O | X |
| Zero-net-emission constraint | X | O | O |

Note: O is 'yes'; X means 'no'.

## 4. Results

### 4.1. Equilibrium carbon price and sectoral emissions

The equilibrium carbon price is estimated to be NZ$85/t$CO_2$e (US$60/t$CO_2$e) in the S1 scenario and NZ$68/t$CO_2$e (US$48/t$CO_2$e) in the S2 scenario (Table 4).[2] The higher price in S1 is easy to understand, given that regulating agricultural emissions as part of NZETS drives up demand for carbon permits. The overall effects of the extended NZETS on the national economy are negative, because this version of NZETS reduces economic output in non-forestry production sectors more than offsets an increased output in the forestry sector. Although emission constraints can function as a positive shock to the forestry sector's output (i.e. increased supply of carbon permits), non-forestry production sectors are forced to reduce emissions through production reduction, switching to less carbon-intensive fuels or purchasing carbon permits, which all generate a downward pressure on sectoral output levels. Among the non-forestry production sectors, emission-intensive sectors are relatively more penalized by the emission caps than others.

Our estimation results seem to be in line with other available estimates, such as those by Concept, Motu, & Public Policy Research (2018). This public consultancy report, sponsored by the NZ Productivity Commission (2018), offers the basis for the modelling;

**Table 4.** Change in sectoral emissions (% relative to baseline).

| Sector | | Emissions under BAU (Mt) | S1 (vs. BAU) | | S2 (vs. BAU) | |
|---|---|---|---|---|---|---|
| | | | Mt | % | Mt | % |
| Agriculture | Horticulture and fruit growing | 6.47 | 3.90 | −39.8 | 5.48 | −15.4 |
| | Sheep–beef cattle and grain farming | 15.7 | 8.76 | −44.2 | 9.99 | −36.4 |
| | Dairy cattle farming | 14.86 | 9.23 | −37.9 | 10.73 | −27.8 |
| | Other agriculture | 1.69 | 1.25 | −26.3 | 1.36 | −19.6 |
| Energy | Stationary energy | 2.84 | 2.69 | −5.5 | 2.67 | −5.9 |
| | Synthetic gases | 1.46 | 1.15 | −21.4 | 1.14 | −21.8 |
| | Nonrenewable electricity | 3.04 | 2.32 | −23.8 | 2.33 | −23.4 |
| | Renewable electricity | 0.38 | 0.38 | −0.1 | 0.38 | −0.1 |
| Manufacturing | Timber processing | 0.19 | 0.23 | 19.4 | 0.22 | 13.1 |
| | Agriculture product processing | 0.02 | 0.01 | −27.4 | 0.01 | −20.8 |
| | Other manufacturing | 5.35 | 5.43 | 1.6 | 5.41 | 1.2 |
| | Industrial processes | 3.39 | 3.48 | 2.6 | 3.45 | 1.7 |
| Other Sectors | Waste | 3.84 | 2.47 | −35.7 | 2.47 | −35.7 |
| | Retail and wholesale trade | 0.06 | 0.06 | 1.5 | 0.06 | 1.5 |
| | Service | 19.43 | 19.87 | 2.2 | 19.72 | 1.5 |
| Total Anthropogenic Emissions | | 78.72 | 61.23 | −22.2 | 37.86[1] | −5.3 |
| Carbon Sequestration from Forest | | −78.72 | −61.23 | 14.6[2] | −37.86 | 11.2 |

[1]This number excludes emissions from agriculture sectors due to the S2 scenario does not account for agriculture emissions. Accordingly, the percentage (5.3%) is the emission reduction level compared with baseline that excludes agriculture emissions; [2]The change of sequestration in both S1 and S2 represents sequestration per tree compared with the baseline.

their outcomes will be incorporated into the government's zero-carbon act.[3] The authors found that the stringent net-zero targets, including agriculture, can be obtained with a carbon price between NZ$76/t$CO_2$e (US$53/t$CO_2$e) and NZ$127/t$CO_2$e (US$89/t$CO_2$e), which substantially overlaps our estimates.[4] Sectoral emissions tend to decline with increased carbon price (Table 3). Under S1, the output of the forestry sector increases 2.4 times from the BAU level; under S2, it increases 1.5 times. This result implies that the gross sequestration capacity required to meet the net-zero emission targets is 61 Mt (i.e. $2.4 \times 26.1$) under S1 and 37 Mt (i.e. $1.5 \times 25.3$) under S2, which are equal to the total emissions generated from all regulated sectors, either including or excluding the agriculture sector, respectively.

Under S1, the largest carbon reduction is from the agricultural sector, followed by those from the energy and waste sectors. Gross emissions decrease by 22% from the BAU level, and this mitigation magnitude is approximately two-thirds of the national reduction target set for 2030. Under S2, wherein agriculture is excluded, gross emissions are reduced minimally, i.e. by 5.3%, presenting a limited contribution to NZ's commitment to the Paris Agreement. This finding suggests that exempting agriculture from mitigation liability may allow NZ to achieve its net-zero emission goal at lower economic costs, but it may not offer considerable help in complying with its committed effort in the post-Kyoto system.

### 4.2. Land use change at emission cost

Our results confirm that the net-zero emission act incentivizes pro-forest land use change (Table 5). For this exercise, we set a low substitution elasticity of 1.5 between forest and the four other agricultural land types and a high elasticity of 20 among the four agricultural land types (Golub et al., 2009; Rae & Strutt, 2011). This setting aims to emulate reality wherein forest-to-agriculture land use conversion, or vice versa, is considerably harder than land use conversion between two different types of agricultural land. The trade-off between forestry and agriculture is apparent, indicating that pricing carbon promotes the forestry sector, but adds costs to agricultural production, curbing agricultural land use. Under S1 and S2, the effects of an equilibrium carbon price on sectoral land use do not differ considerably (except for horticulture).

**Table 5.** Land use change by sector in hectares (% of baseline).

| | | | Agricultural Land | | | |
|---|---|---|---|---|---|---|
| *Scenario: S1* | *Total* | *Forest* | *Grassland* | *Scrubland* | *Cropland* | *Other* |
| Forestry | 75.9 | 74.9 | 89.3 | 77.1 | 92.1 | 88.4 |
| Horticulture | −10.0 | −71.7 | −5.8 | −11.9 | −4.4 | −6.3 |
| Sheep–beef | −8.9 | −70.9 | −1.6 | −7.9 | −0.1 | −2.0 |
| Dairy farming | −4.2 | −69.7 | 2.3 | −4.3 | 3.8 | 1.8 |
| Other agriculture | 2.0 | −67.1 | 11.1 | 4.0 | 12.8 | 10.6 |
| *Scenario: S2* | *Total* | *Forest* | *Agricultural Land* | | | |
| | | | *Grassland* | *Scrubland* | *Cropland* | *Other* |
| Forestry | 52.8 | 56.3 | 34.9 | 31.5 | 33.8 | 34.8 |
| Horticulture | 1.7 | −50.1 | 6.3 | 3.7 | 5.5 | 6.3 |
| Sheep–beef | −6.1 | −53.3 | −0.8 | −3.3 | −1.6 | −0.8 |
| Dairy farming | −3.0 | −52.0 | 1.8 | −0.8 | 1.0 | 1.7 |
| Other agriculture | −3.2 | −51.5 | 3.0 | 0.4 | 2.2 | 2.9 |

### 4.3. Impact on the forestry sector

The net-zero emission constraint introduces a positive shock to the forestry sector (Table 6). For this analysis, we first define timber yield $f$ as a function of optimal rotation age $T$, where $\alpha_1$, $\alpha_2$, and $\alpha_3$ are parameters, as given in Equation 1.

$$f(T) = \alpha_1 * T^{\alpha_2} * \exp(-\alpha_3 * T) \tag{1}$$

In our model, forest land owners are set to maximize the NPV of their land over all future periods from a mixture of the following three perspectives: timber sales (NPV1), carbon permit sales (NPV2), and emission liability (NPV3). Each of the three NPV measurements reflects only one particular aspect of the owner's interest and is optimized only for a single rotation cycle (Kooten et al., 1995; Sands & Kim, 2008). For his/her final decision, the forest land owner will then synthesize all three aspects (Equations 2–4) and consider the entire future rotation cycles, rather than a single cycle, as shown in Equation 5.

$$NPV_1(T) = [p_t * f(T) - c_h] * \exp(-r * T) - c_g \tag{2}$$

$$NPV_2(T) = \int_0^T p_c k f'(x) \exp(-r * x) dx \tag{3}$$

$$NPV_3(T) = -p_c * k * (1 - \beta) * f(T) * \exp(-r * T) \tag{4}$$

$$NPV_4(T) = \frac{NPV_1(T) + NPV_2(T) + NPV_3(T)}{1 - exp(-r * T)} \tag{5}$$

where $p_t$ and $p_c$ are the timber and carbon prices, respectively; $c_h$ is the harvest cost; $c_g$ is the planting cost; $f(T)$ represents the timber yield per hectare; $k$ is the factor that converts cubic metres of timber into metric tons of carbon; $\beta$ is set as a pickling parameter to describe the carbon stored permanently in wood; and $r$ is the discount rate.

Across a single rotation length, the optimal harvest age decreases from 27 years under S1 to 26 years under S2, and timber price slightly drops from the baseline of NZ\$160/ha (US\$112/ha) to NZ\$158/ha (US\$111/ha) under both scenarios. This result suggests that the low carbon price (NZ\$68/t$CO_2$e) under S2 relative to that under S1 leads to less tree

**Table 6.** Calibrated Results from the Forest-growth Sub-model.

| | *Scenario* | |
|---|---|---|
| | *S1* | *S2* |
| NPV of forest from owner's perspective* (NZ\$/ha) | 53,493 | 51,747 |
| NPV of forest given a single rotation-age cycle (NZ\$/ha) | | |
| Total | 46,423 | 42,588 |
| Revenue from timber sales | 30,294 | 29,911 |
| Revenue from carbon permit sales | 16,129 | 12,677 |
| Emissions liability | −11,430 | −9,069 |
| Partial equilibria estimated for key variables | | |
| Rotation age (year) | 27 | 26 |
| Timber yield (per hectare) | 556 | 539 |
| Timber price (NZ\$/ha) | 158 | 158 |

Note: * All future rotation age cycles have been considered.

planting and earlier logging. Furthermore, a relatively short rotation age reduces the amount of planting trees.

Forest land owners make positive profits even when discount rates are as low as 4%, although their profits depend on their adopted perspective. Overall, high carbon prices under net-zero emission targets positively affect the forestry sector output by promoting the sales of timber products (NPV1) and carbon permits (NPV2). NPV1 and NPV2 move in the same direction, because high carbon prices incentivize tree planting, contributing to timber product output growth. The magnitude of the shock is greater under S1 than under S2 due to higher carbon prices under the former. The increased value of forest under high carbon price, in turn, drives up emission liabilities or the costs of timber harvesting or anti-forest land conversion, which are indicated with a negative sign (NPV3).

### 4.4. Economy-wide policy-compliance costs

NZETS extended under the zero-emission act has a negative impact on GDP and employment due to the increased substitution of foreign imports for domestic goods under the carbon price (Figure 4). This negative shock to GDP (1.2%–1.4% of the baseline level) can be regarded as a cost that is required to comply with the stricter carbon regulation (i.e. policy-compliance cost). Labour and capital prices also tend to decline due to reduced industrial output. The magnitude of shock is greater in emission-intensive sectors than in others; thus, factors tend to move away from these sectors. Notably, policy-compliance costs, measured in GDP loss, are greater under S1 (1.4%) than under S2 (1.2%), but their difference is marginal compared with that in GHG reductions (22.2% versus 5.3%). This result may suggest that regulating agriculture within NZETS can be cost-effective.

Our compliance cost estimates are substantially lower than those found in NZIER (2018), ranging from 5% to 15% of the baseline GDP. Their estimates, however, are based on carbon prices, i.e. NZ\$150/t$CO_2$-e (US\$105/t$CO_2$e) to NZ\$450/t$CO_2$e (US \$315/t$CO_2$e) in 2016 prices, exceeding a widely adopted range of NZ\$76/t$CO_2$e (US \$53/t$CO_2$e) to NZ\$127/t$CO_2$e (US\$89/t$CO_2$e) by a factor of ≤5.9 (Concept et al., 2018). Given such high carbon prices, they found considerably larger GDP loss than our estimates. The Productivity Commission discusses why NZIER (2018) estimates differ considerably from the international estimates of carbon prices consistent with

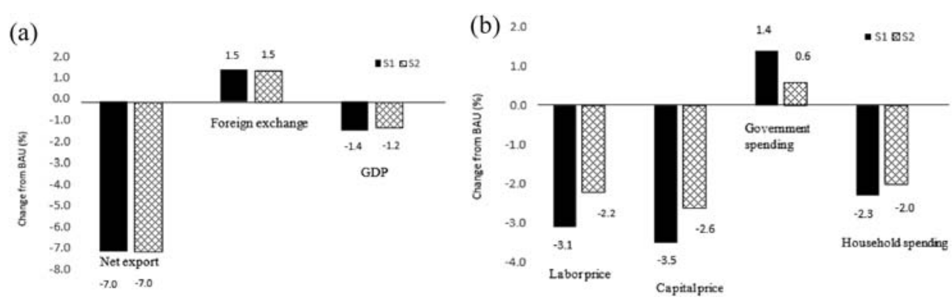


**Figure 4.** Simulated changes in economic indicators: (a) Trade-relevant variables; (b) Macro-economy variables.

**Table 7.** Sectoral output (of baseline).

| | Sector | S1 Dollar value ($m NZD) | S1 % | S2 Dollar value ($m NZD) | S2 % |
|---|---|---|---|---|---|
| Agriculture | Horticulture and fruit growing | 2959.9 | −41.3% | 3946.6 | −15.4% |
| | Sheep-beef cattle and grain farming | 4309.3 | −46.3% | 5171.2 | −36.4% |
| | Dairy cattle farming | 5576.6 | −39.0% | 6506.1 | −27.8% |
| | Other agriculture | 6026.9 | −26.1% | 6887.9 | −19.6% |
| Forestry | Forestry | 12500.9 | 130.8% | 8152.8 | 49.5% |
| Energy | Stationary energy | 10764.2 | −7.1% | 10764.2 | −5.9% |
| | Synthetic gases | 1185.5 | −25.9% | 1354.8 | −21.8% |
| | Non-renewable electricity | 4232.6 | −28.4% | 4837.3 | −23.4% |
| | Renewable electricity | 11946.6 | 0.0% | 11946.6 | 0.0% |
| Manufacture | Industrial processes | 22195.2 | 1.8% | 22195.2 | 1.7% |
| | Timber processing | 22407.6 | 19.6% | 20540.3 | 13.2% |
| | Agriculture product processing | 33139.6 | −29.3% | 37873.8 | −21.0% |
| | Other manufacturing | 95607.7 | 1.5% | 95607.7 | 1.2% |
| Others | Waste | 1556.3 | −40.3% | 1556.3 | −35.7% |
| | Retail and wholesale trade | 50692.6 | 1.3% | 50692.6 | 1.0% |
| | Service | 296384.3 | 2.4% | 296384.3 | 1.5% |

the 2 °C scenarios, which are generally below US$130 (in 2016 prices). In the end, the commission firmly supports the estimate of Concept et al. (2018), with which we concur that the carbon prices estimated by NZIER lack credibility. Part of the difference may also originate from their methodological limitation. In contrast with our model, the forestry sector and land use changes are not explicitly modelled in their work.

The two scenarios generate a similar impact on net export, which is approximately a 7% reduction. For this analysis, we assume that other foreign economies do not impose strict carbon regulations as NZ does. Hence, stricter carbon control makes NZ's local intermediate inputs relatively more expensive than foreign imports, encouraging imports while penalizing exports. A negative impact on net export (and current account) also has an effect on foreign exchange rates. Increased demand for foreign imports leads to increased demand for foreign exchange, which in turn, creates an upward pressure for foreign exchange rate and results in local currency depreciation.

As shown in Figure 4, real GDP declines by 1.4% and 1.2% under each scenario. This effect can be explained by the decrease in sectoral output (Table 7). The reduction in sectoral output decreases the demand for the factor used in most sectors, except for forestry and its related sectors. Labour and capital prices will generally fall, leading to a decline in household consumption in both scenarios.

## 5. Conclusions

In this study, we examined a shock to the NZ economy arising from the transition to a low-carbon society by applying a CGE model coupled with an endogenous forest growth module. Our results show that the inclusion of the agricultural sector in NZETS can yield a 22% reduction in gross emissions, which is approximately two-thirds of NZ's emission reduction target for 2030. However, if the agricultural sector is excluded, a gross emissions reduction is estimated to be only 5% from the baseline level. This condition suggests that NZETS alone may be insufficient to ensure NZ's successful commitment to the Paris Agreement if it fails to cover agricultural emissions, even when net-zero emission targets are met.

Our potential contribution to the literature lies not only in our attention to NZ's recent mitigation proposal, which has understudied potential impacts, but also in advanced methodological features presented in our modelling approach. Instead of adopting exogenously given carbon prices and sequestration capacity, which is prevalent in the existing literature, we explicitly modelled the interaction between carbon sequestrations from forestry to other economic sectors to draw realistic pictures.

Overall, higher carbon prices under the extended NZETS introduce a negative shock into the economy in terms of GDP. Regulating agricultural emissions within NZETS is costly but can be cost-effective, given that the difference in policy compliance costs (GDP loss of 1.4% versus 1.2%) is marginal compared with that in GHG reductions (22.2% versus 5.3%). Increased demand for foreign imports under high carbon prices also negatively affects net export (current balance) and the purchasing power of the local currency.

This study limits its research scope to NZ, but it conveys crucial policy implications for other economies. Our potential contribution to the literature is twofold. First, from a methodological perspective, our F–CGE model demonstrates how conventional economic accounts can be linked to physical accounts, such as those for land use and carbon emissions, and how a top-down model (e.g. CGE) can be coupled with a bottom-up model (e.g. forestry growth model). Second, from a policy perspective, our analysis is timely, given that existing studies frequently fail to offer a completely realistic picture on the potential costs of emission regulations. For example, a weak linkage between emission constraints and a natural carbon sink, such as forestry, which is often the case in many studies, can lead to potential overestimation, consequently discouraging proactive mitigation efforts. By contrast, our results, wherein a natural carbon sink is considered part of the endogenous optimization procedure, reduce such potential bias.

In summary, our results imply the need to regulate agricultural emissions within NZETS in connection with the net-zero emission targets. The additional compliance costs required for the regulation are relatively marginal compared with the estimated mitigation effects, and thus, seem bearable from a cost-effectiveness standpoint. However, we consider NZETS as the only mitigation measure in this study. In the future, we plan to extend our research scope to include other interventionist tools in implementation, such as the energy strategy and Freshwater Management. We also consider a dynamic CGE analysis as a potential follow-up study to test time-varying emission constraints.

## Notes

1. Radiata pine accounts for 90% of the planted forest area, and Douglas fir is the second most popular plantation species in NZ.
2. The exchange rate of 0.7 US$/NZ$ in 2016 is used throughout this paper.
3. Refer to the government website for a summary of the modelling results at https://www.mfe.govt.nz/have-your-say-zero-carbon.
4. Carbon price in the study of Concept et al. (2018) is given in 2050 dollar, but this future value in our study is converted to 2016 dollar. For this conversion of the time value of money, we assume an inflation rate of 2%, which is the historical average over the last couple of decades.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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