The economic implications of national climate change mitigation strategies on the Auckland region

21 July 2022

m.e research

Tātaki Auckland Unlimited (2022). The economic implications of national climate change mitigation strategies on the Auckland region.

Prepared by Market Economics Ltd for Tātaki Auckland Unlimited.

Report author(s): Juan J. Monge, Garry W. McDonald and Robert Cardwell

Director approval: Nicola J. McDonald

www.me.co.nz

November 2022

ISBN 978-1-99-118501-3 (PDF)

Executive Summary

To mitigate the effects of climate change, governments around the world have agreed, under the Paris Agreement in 2016, to limit the global average temperature increase to 1.5°C above pre-industrial levels. To comply with this agreement, the NZ Government enacted the Climate Change Response (Zero Carbon) Amendment Act 2019. The Act established the following Greenhouse Gas (GHG) emissions reduction targets:

- reduce emissions from biogenic methane to 24-47% below 2017 levels by 2050, and
- reduce net emissions from all other GHGs to zero by 2050.

The Act also established the Climate Change Commission (CCC) to provide independent expert advice and monitoring to keep Aotearoa-NZ on track to meet these targets. "Ināia tonu nei: a low emissions future for Aotearoa" (CCC, 2021) presents transition pathways to a thriving, climate-resilient and low emissions Aotearoa-NZ. "Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan" provides an overarching Tāmaki Makaurau response to climate action, focusing on greenhouse gas (GHG) emissions reduction targets, and preparation for the impacts of climate change.

In this study for Tātaki Auckland Unlimited, we assess the economic consequences of the proposed pathways considered under Ināia tonu nei and Te Tāruke-ā-Tāwhiri on Auckland region and the rest of Aotearoa-NZ.

How are economic consequences assessed?

To understand the economic implications of potential pathways to a low carbon economy, the CCC used the Climate PoLicy ANalysis (C-PLAN) model (Winchester and White, 2022). In this study, we adapt C-PLAN to better reflect the makeup of the Aotearoa-NZ economy and separate out implications for Auckland and the rest of Aotearoa-NZ. We trace transition on an annual basis over a 30-year period.

What emissions, trading schemes, and emissions reduction technologies are considered?

GHG emissions are linked to two potential sources: 1) combustion-based GHG emissions e.g., CO_2 from coal, gas, and refined oil use, and 2) process-based GHG emissions including CO_2, CH_4, N_2O and F-gas emissions. Industries reduce GHG emissions by substituting between energy types (e.g., changing to renewables), becoming more energy efficient (i.e., using less energy per unit of production), and through other measures (e.g., more efficient feed utilisation in farming).

Emissions Trading Schemes (ETSs) are employed to mitigate the effects of climate change by incentivising a reduction of GHG emissions through a price signal. Producers and consumers buy permits to emit GHGs that result from their actions. The permits available for purchase are determined by an ETS cap, which is based on specific GHG reduction goals. If more emissions are generated than are permitted by the caps, then permit prices are generated. Some sectors receive free permits while they adapt to decreasing GHG caps.

Advanced and emergent technologies are also considered as low-emissions alternatives to conventional technologies that will be highly impacted by carbon prices e.g., electric vehicles, methane inhibitors for dairy, sheep and beef farming, geothermal electricity with carbon capture and storage, and electric and bioheat for industries heavily dependent upon industrial heating. As the cost of conventional technologies increases, due to increasing carbon prices, advanced technologies, with their lower GHG footprints, become more affordable.

What scenarios are used?

The model reports the net impacts of change for key economic indicators (e.g., industry output, household consumption, GDP and employment) under two scenarios. Firstly, the baseline scenario considers current climate policies, uptake of electric vehicles, and projected industry growth trends. Secondly, a policy scenario, which builds on the baseline scenario, also considers emerging advanced technologies (e.g., methane inhibitors, renewable energy generation) and decreasing ETS GHG caps that align with the targets set out in the Zero Carbon Act 2019.

The policy scenario builds on the baseline scenario by adding reduction targets for GHG emissions. Specifically, two ETSs are included: 1) for biogenic methane from dairy, sheep and beef farming with a 2050 target of 47% below 2017 levels, and 2) for all other GHGs with a net-zero target by 2050.

Results

Key scenario results are presented for emissions, price of GHG permits, and impacts on industry, households, regional GDP, and employment.

E1. Emissions

Under both scenarios, Auckland's total GHG emissions reduce over time, as is the case across the rest of Aotearoa-NZ. The policy scenario is more ambitious and produces an 18-23% reduction in emissions compared to the baseline scenario for the Auckland region. Reductions in road transport (including for households) and electricity contribute the most to lowering emissions in Auckland. A major driver of this change is the increasing use of electric vehicles in Auckland. In the rest of Aotearoa-NZ the greatest reductions come from agriculture. Emissions decrease linearly over time and reach their 2050 Zero Carbon Act targets.

E2. Price of GHG permits

The permit price for the ETS is the same for Auckland and the rest of Aotearoa-NZ. The price per unit increases as the availability of permits decreases. By 2050, the unit price for one tonne of CO_2-e could reach NZ$350. For biogenic methane, the permit price increases rapidly because of the decreasing ETS cap initially, but once methane reducing technologies are adopted in 2025, the price decreases again. Technology solutions have limits, and once these are reached (around 80-90% for farming sector uptake), the price drastically increases. Future pricing may be influenced by setting further targets.

E3. Industry impacts

Fig. E1a shows the change in output from various primary and manufacturing sectors in Auckland and the rest of Aotearoa-NZ under both scenarios. In terms of the primary sectors, the ETS caps under the policy scenario have the greatest influence in reducing agricultural emissions (dairy, sheep and beef sectors) in the rest of Aotearoa-NZ. Auckland's primary industries only make a small contribution to regional emissions, so the effects felt are minimal. In terms of manufacturing, Fig. E1b shows the ETS caps (policy scenario) affect mostly the refined oil, dairy and meat processing sectors across Aotearoa-NZ. Auckland's manufacturing sectors are also affected by the ETS caps, with refined oil outputs decreasing as more electric vehicles are introduced, lessening our reliance on the internal combustion engine.

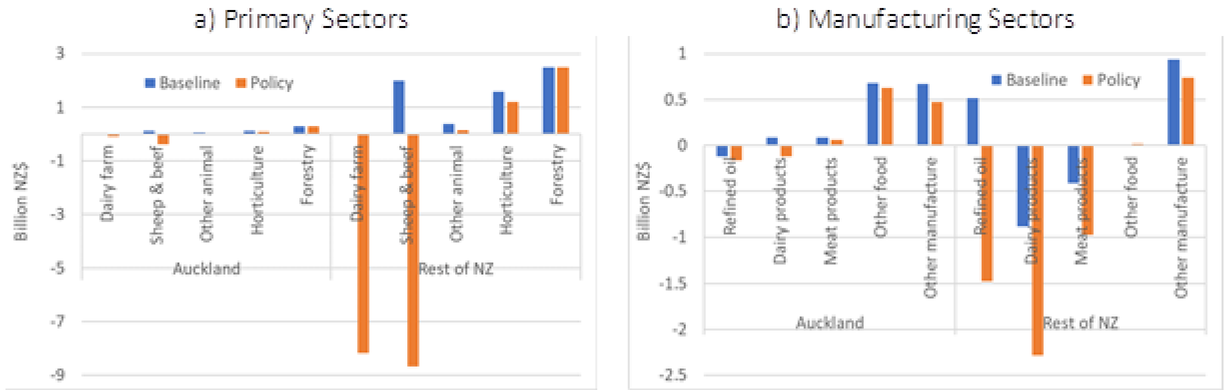

Fig. E1. Absolute change in output from various primary and manufacturing sectors in the 2014-2050 period under the baseline and policy scenarios for Auckland and the rest of Aotearoa-NZ (Billion NZ$)

Impacts are also felt in the electricity generation and transport industries. For the electricity sector, Fig. E2a shows that both Auckland and the rest of Aotearoa-NZ experience a lift in output from green energy generation (geothermal, wind and solar), and conversely, a reduction in output from coal and gas sources over time under both scenarios. The decreasing output from conventional geothermal technology is picked up by new geothermal technology with carbon capture and storage under the policy scenario. Road and private transport emissions (Fig. E2b) reduce because of the electrification of vehicle fleets over time, while air transport emissions increase under both scenarios.

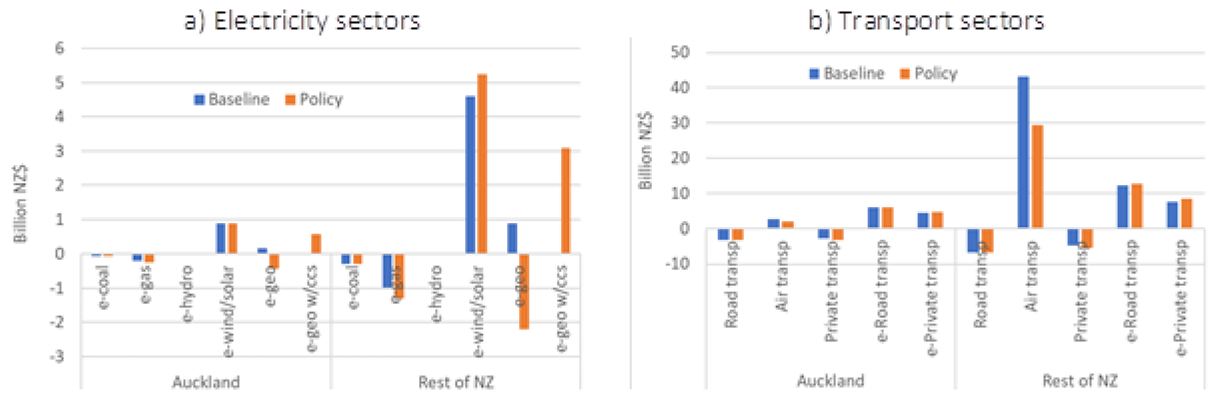

Fig. E2. Absolute change in output from various electricity and transport sectors in the 2014-2050 period under the baseline and policy scenarios for Auckland and the rest of Aotearoa-NZ (Billions NZ$)

E4. Household impacts

Fig. E3 shows the change in household consumption of a variety of food products. The consumption of dairy and meat products decreases in Auckland under the policy scenario. This is a result of the ETS cap on biogenic emissions restricting output from dairy, sheep and beef farming in the rest of Aotearoa-NZ and the ensuing interregional import price increase in Auckland. Consumer welfare, an overarching measure of impact for households, decreases in Auckland region (-5%) and increases in the rest of Aotearoa-NZ (1.1%) for the policy scenario.

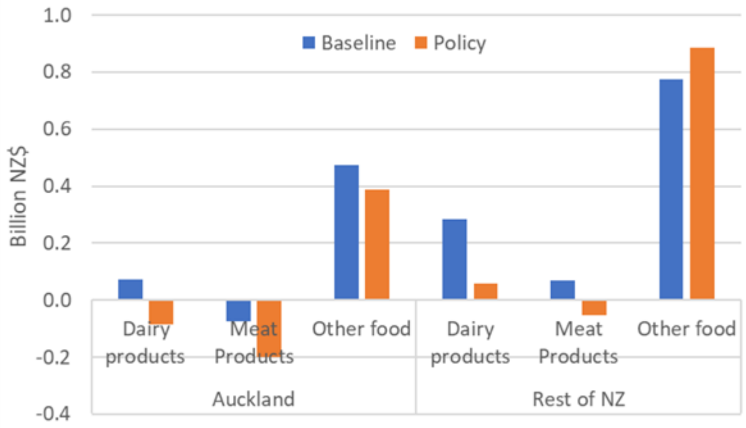

Fig. E3 Absolute change in the consumption of various food products by households in the 2014-2050 period under the baseline and policy scenarios for Auckland and the rest of Aotearoa-NZ (Billion NZ$)

E5. Regional GDP impacts

Fig. E4 shows the absolute change in GDP under both scenarios. In relative terms, the GDP in both regions increases at a lower rate under the policy scenario. The Auckland economy is slightly more impacted, compared with the rest of Aotearoa-NZ.

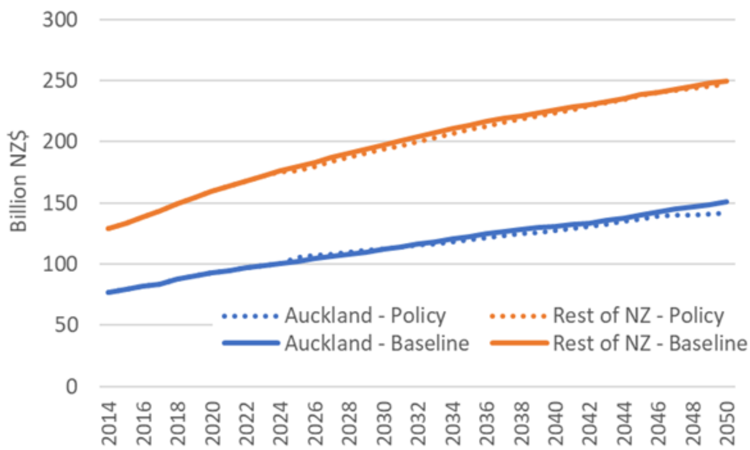

Fig. E4. Regional GDP for Auckland region and the rest of Aotearoa-NZ under both baseline and policy scenarios

E6. Employment impacts

By 2050, job losses under the policy scenario for Auckland amount to around 1% (i.e., about 15,000 of 1.5 million employees). Net losses for Auckland are felt mostly in agriculture and geothermal energy (generation and supply). The worst affected occupations for job losses are in the farming and road transport sectors, e.g., farmers, transport professionals, truck and train drivers, and other manufacturing roles. The net result of the transition to a low carbon future does not greatly change the occupation profile of the Auckland economy. There is instead a gradual transition as more green jobs emerge and supersede carbon-intensive jobs.

Contents

Figures

1 Introduction

To mitigate the effects of climate change, governments around the world agreed under the Paris Agreement in 2016 to limit the global average temperature increase to 1.5 degrees Celsius above pre-industrial levels. To comply with this agreement, the New Zealand government enacted the Climate Response (Zero Carbon) Amendment Act 2019 providing a framework to "develop and implement clear and stable climate change policies" (Parliament of New Zealand, 2019). The Zero Carbon Act established the following Greenhouse Gas (GHG) emissions reduction targets:

- reduce net emissions of all GHGs (except biogenic methane) to zero by 2050, and
- reduce emissions of biogenic methane to 24-47% below 2017 levels by 2050.

The Zero Carbon Act also established a new, independent Climate Change Commission (CCC) to "provide expert advice and monitoring to help keep successive governments on track to meeting long-term goals" (Parliament of New Zealand, 2019). Hence, while the government set the 2050 targets through the Zero Carbon Act, the CCC's role is to provide independent, evidence-based advice on how to reach the targets, i.e., pathways. As part of this advice, the CCC's "Inai Tonu Nei: a low emissions future for Aotearoa" report has presented pathways to transition to a thriving, climate-resilient and low emissions Aotearoa (Climate Change Commission, 2021a).

The CCC relied on a suite of models to support evidence on the techno-economic and social implications of the transition pathways to a climate-resilient and low emissions future. The different models complement each other as some are bottom-up and focus on specific sectors in the economy (e.g., energy and transport) while others focus on economy-wide interactions and their macroeconomic implications. The model built to assess the macroeconomic implications of the proposed transition pathways is the Climate Policy Analysis (C-PLAN) model, which is a global Computable General Equilibrium (CGE) model that places the New Zealand economy in a global context (Winchester and White, 2022). Most CGE models used to date in the climate change mitigation space are either at the national or global scale as most use the widely accepted Global Trade Analysis Project (GTAP) dataset (Burniaux and Truong, 2002).

Although C-PLAN has been a key steppingstone to inform policymakers that the New Zealand economy can still grow strong with the proposed transition pathways, there is still a need to assess the implications on large cities as these are responsible for the largest percent of carbon dioxide emissions due to the sheer number of people. For example, the most populated region in New Zealand, Auckland, accounted for the largest share of the country's household emissions (34%) as well as the third largest share of industry emissions (11%) after Waikato region and Canterbury region (Statistics New Zealand, 2021a). Hence, the mitigation actions taken in regions like Auckland will substantially help in achieving the ambitious targets New Zealand has established as a nation. However, it is in the district/regional councils' best interest to ensure that the regional mitigation actions are economically affordable and socially acceptable.

Tātaki Auckland Unlimited has requested M.E Research to model and analyse the potential macroeconomic implications from national climate mitigation strategies on the Auckland region economy. M.E Research has developed both regional economic datasets (i.e., Social Accounting Matrices or SAMs) (Smith et al., 2015) and multi-regional CGE models (McDonald et al., 2021), over several years, which have been previously used to delve deeper into the implications of national policies/strategies/trends on regional economies. These datasets and models were modified for the specific urban context of Auckland region and used in this study to assess the potential macroeconomic implications of the CCC's transition pathways on the Auckland region economy. Auckland region is of particular interest to the nation as:

- it is home to the largest share (34%) of the country's population (Statistics New Zealand, 2021b),
- it is the country's largest economic region contributing 38% of the nation's GDP (Statistics New Zealand, 2021c),
- it is the country's third highest emitting region in terms of carbon dioxide equivalent (CO_2e) (Statistics New Zealand, 2021a):
  - Highest for overall carbon dioxide and fluorinated gases,
  - Highest carbon dioxide emissions from households,
- it has announced its own net zero targets by 2050 (Auckland Council, 2020).

Besides measuring the impacts that directly affect the regional industries, an advantage of using a multi-regional economy-wide model is that it also considers the indirect impacts exerted on Auckland region's households from consuming commodities produced by affected sectors outside of Auckland region, e.g., higher milk prices due to additional emissions costs incurred by the dairy industry in the Waikato region. Another advantage offered by CGE models is the explicit treatment of the labour market enabling the assessment of employment impacts not only for the sectors negatively affected but also for the ones that will benefit from the transition, i.e., new renewable energy sources generating more green jobs. When mapping such employment implications to the occupation and skillsets in high demand in the future, councils and their economic development agencies will be able to assess the education/training requirements for the new green jobs.

Hence, the main objective of this study was to assess the direct and indirect economic implications from national climate mitigation strategies on the Auckland region economy using as a reference the macroeconomic analysis of the transition pathways undertaken by the CCC and used as evidence to support their recommendation and advice to government. M.E Research engaged with key Auckland Council personnel to modify certain assumptions considered by the CCC in the national assessment to appropriately represent Auckland's regional economy and transition pathways. The economic assessment was also accompanied by an assessment of the occupations and skillsets required in transitioning to a low emissions economy.

1.1 Computable General Equilibrium

Although the origins of CGE models can be traced back to the 18th century, the modern form of these models did not begin to appear until after the mathematical definition of the general equilibrium by Walras (1874), the matrix representation of an economy in the form of input-output (I-O) tables by Leontief (1936), the inclusion of the "Walrasian equilibrium" in the Arrow-Debreu model by Arrow and Debreu (1954), and the development of the first numerical and empirical CGE model by Johansen (1964). Up to date, these models have enjoyed considerable influence in assessing economy-wide impacts and policy development, particularly via the World Bank, the Centre of Policy Studies at Monash University (Australia) and the International Food Policy Research Institute.

Both I-O and CGE models are stylised models that may explicitly model the interdependencies between sectors of global, national, and regional economies. The most important advancement that sets I-O and CGE models apart is the more realistic representation pricing, substitution, and transformation behaviour by economic agents in the latter. While I-O models consider Leontief production functions where inputs are applied in fixed proportions without room for substitution, CGE models explicitly consider input substitution non-linear production functions – including the Leontief production function as a special case. Hence, with substitution, the proportions of inputs going into a production function change based on the relative price changes of different inputs.

For an introduction to CGE models please refer to Hosoe et al. (2010), and for detailed information on the diverse types of CGE models that exist please refers to Dixon and Jorgenson (2013a, 2013b). In this work, a recursive dynamic CGE model tracks factor (labour and capital) stocks by year, assuming equilibrate each year, and uses the endogenous variables of one iteration as exogenous variables for the next iteration.

2 Methodology

The model used for this study is based on the C-PLAN model used by the CCC for their consultation/draft recommendations (Winchester and White, 2022). C-PLAN is based on three globally recognised CGE models: the Massachusetts Institute of Technology's Emissions Prediction and Policy Analysis (EPPA) model (Paltsev et al., 2005) and the European Commission's General Equilibrium Model for Economy-Energy-Environment (GEM-E3) (Capros et al., 2013). Hence, both the C-PLAN model and the one used in this study are multi-regional, recursive dynamic CGE models.

The main difference between the model used in this study and C-PLAN is the use of different social accounting matrices (SAMs) and, as a result, different sectorial and institutional accounts. C-PLAN uses the GTAP dataset and focuses on New Zealand as the region of interest and its interaction with the economy of the rest of the world. While the GTAP dataset covers all economic sectors within the New Zealand economy, the sectoral aggregation reflects more the make-up of the global rather than New Zealand economy.

As shown in Figure 1, the model used in this study defines Auckland as the region of interest and relates it to the economy in the rest of New Zealand – the interactions with the rest of the world occur exogenously. The model uses as its main inputs two inter-related Social Accounting Matrices (SAMs): one for Auckland region and one for the rest of New Zealand. A full mathematical specification of the procedure to generate both SAMs is available in Smith et al. (2015).

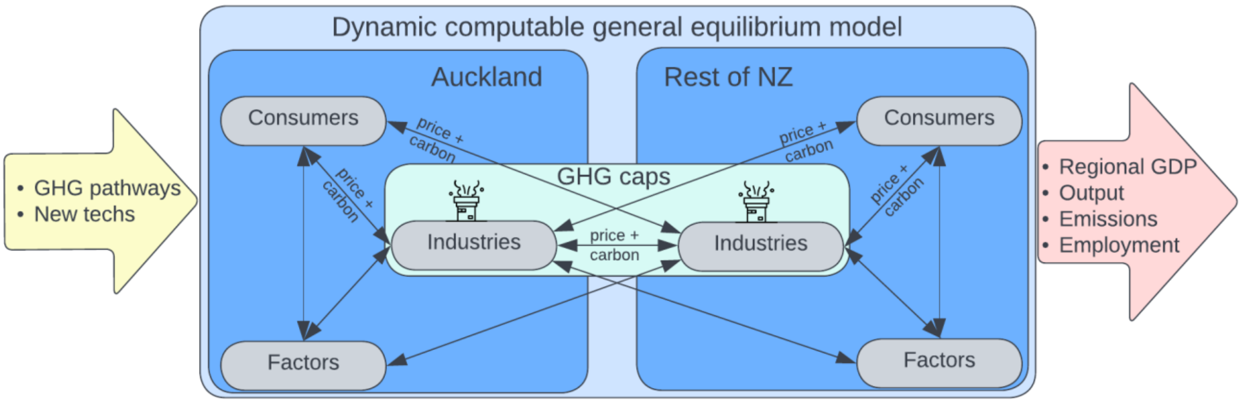

Figure 1. Graphical representation of the CGE model including inputs (yellow), outputs (red), economic agents (grey), regions (blue), interactions (arrows), the Greenhouse Gas (GHG) caps (green) imposed on polluting industries, and the resulting increase in commodity prices due to the addition of a carbon price

The essential mechanism of the model is to contrast the likely evolution of both the Auckland region and New Zealand economy, based on economic principles and expected technology/policy trends, under:

1. a future baseline scenario driven by current climate policies such as the NZ Emissions Trading Scheme (ETS), and
2. a future with decreasing GHG limits/caps that eventually reach the targets set in the Zero Carbon Act by 2050.

CGE models typically assume that an economy is initially at equilibrium (i.e., providing a benchmark) and converges to a new equilibrium in response to an exogenous 'shock' (i.e., a counterfactual scenario). These models converge to new equilibria using a set of microeconomic principles and macroeconomic accounting relationships. From a microeconomic perspective, CGEs rely on a couple of first-order conditions that guarantee the convergence to an optimal equilibrium: (1) profit maximization subject to a zero-profit condition to identify optimal production levels by various industries and (2) utility maximisation subject to a full-budget allocation to identify optimal consumption levels by households. An agent's consumption and production behaviour are dependent on the equilibrium prices of commodities and factors of production that satisfy various (Walrasian) market-clearing conditions (i.e., supply must equal demand). From a macroeconomic perspective, a set of closure rules and institutional accounting identities (e.g., savings and investment) ensure that the model behaves well and is tractable.

Our model is specified as a Mixed Complementarity Program (MCP) in the Mathematical Programming Systems for General Equilibrium (MPSGE) package (Rutherford, 1999) as a sub-system of the General Algebraic System (GAMS) (Brooke et al., 1998). An Agile Development Approach was followed in developing the model, with different versions of the GAMS code tracked using Git processes using cloud-based repositories at Gitlab.com. We can provide either an electronic copy of the GAMS code or a link to the Gitlab repository if requested.

2.1 Production

Commodity production follows a nested CES production function, where the inputs are intermediate inputs (commodities), energy and the factors of production as shown in Figure 2 through a generic "nest" diagram representing most industries included in the model. Although the inputs are nested, using a CES functional form, different substitution patterns exist within the various sub-nests and represented by a substitution elasticity parameter (σ) with different subscripts. Among the substitution patterns, the Leontief (σ = 0) and Cobb-Douglas (σ = 1) substitution patterns are exceptional cases. For example, the intermediate inputs' nest follows a Leontief structure where commodities are non-substitutable with the proportion of commodities required to produce a unit of commodity output remaining constant as represented by the perpendicular lines in Figure 2. The rest of the nests follow different substitution patterns and are differentiated by their respective subscripts.

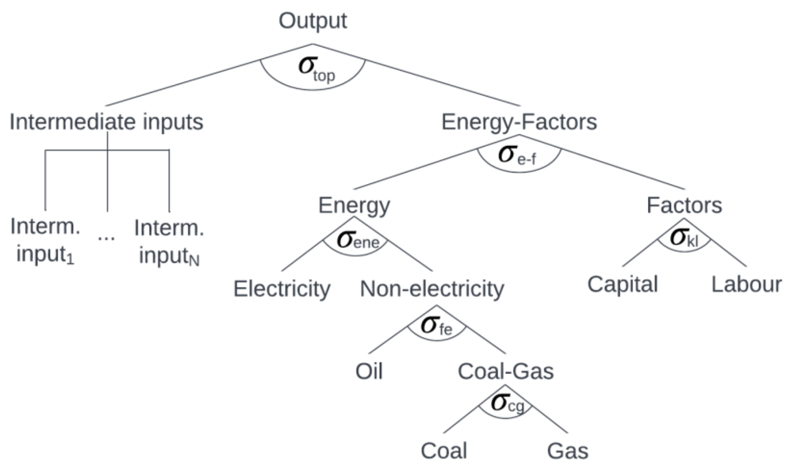

Figure 2. Generic production nest representing most of the industries considered. Perpendicular lines represent a Leontief production structure with an elasticity of substitution (σ) of zero. Subscripts represent different substitution levels: *top* between intermediate inputs and the energy-factors composite; *e-f* between the energy and factors composite; *ene* between electricity and non-electricity; *kl* between capital and labour nest; *fe* between oil, coal and gas energy, and *cg* between coal and gas.

Although the nesting structure in Figure 2 is very similar to the rest of the industries, specific sectors such as the electricity sector (using various technologies) follow a slightly different structure as depicted in Figure 3. The structure that forms the energy-factor aggregate is similar for all sectors. The main difference across sectors is in the use of additional branches (most in the top nest) to accommodate the inclusion of additional resource endowments such as land and/or Technology Specific Factors (TSF). As explained in the following sections, these additional resources exogenously control the output from certain industries over time. For example, as shown in Figure 3 for the electricity sectors, TSFs to follow exogenous electricity projections developed through an external source. Winchester and White (2022) provide a more comprehensive and detailed description of the rest of the industries' nesting structures.

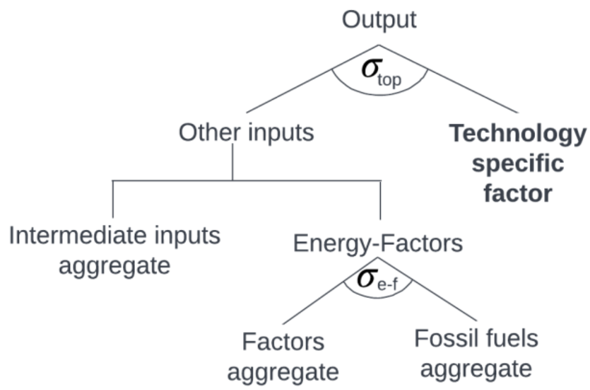

Figure 3. Production nest for electricity technologies with a technology-specific factor (in bold font)

2.2 Consumption

Households and government maximise their respective utilities by adjusting the consumption of commodities subject to budget constraints. Figure 4 shows the nesting structure used to represent consumption patterns of representative households in both Auckland region and the rest of New Zealand. Government consumption and investment expenditures are determined using a similar nesting structure but with less sub-nests.

The household consumption nest accommodates two utility specifications (i.e., CES and Stone-Geary) with different consumption preference implications. More specifically, the non-transport branch is a CES utility function, common in the CGE literature due to its tractability, whereas the transport branch follows a Stone-Geary utility specification (Chen, 2017). The reason behind using a Stone-Geary specification, more specifically the resulting Linear Expenditure System (LES), is to simulate non-homothetic preferences, which is a more realistic assumption than the homothetic preferences resulting from a CES specification (Chen, 2017; Matsuyama and Ushchev, 2017).[1] As discussed in Winchester and White (2022), Stone-Geary preference parameters were chosen to match the consumption of the transport commodities to the external projections supplied by the bottom-up models. Stone-Geary specifications are not used for non-transport commodities as the various land-use, production and energy-efficiency constraints/inertia were key drivers/determinants of the baseline consumption of these commodities.

[1] The assumption of homothetic preferences implies that the budget share of each good is independent of the household expenditure or, in other words, all goods are needed. Non-homothetic preferences differentiate between necessities and luxuries, which is more in line with empirical observations.

As shown in Figure 4, households can choose between commercial (e.g., taxis, buses, and airplanes) and household transport (privately-owned motor vehicles). The latter results from consuming products from services (e.g., vehicle maintenance and insurance) and the "vehicle services" composite, which consists of the consumption of refined oil products and motor vehicles. The substitution elasticity of the "vehicle services" composite ($\sigma_{o\text{-}m}$) is critical as it governs the substitution behaviour when oil prices rise by spending more on motor vehicles and less on fuel, i.e., price-induced preference for more fuel-efficient vehicles.

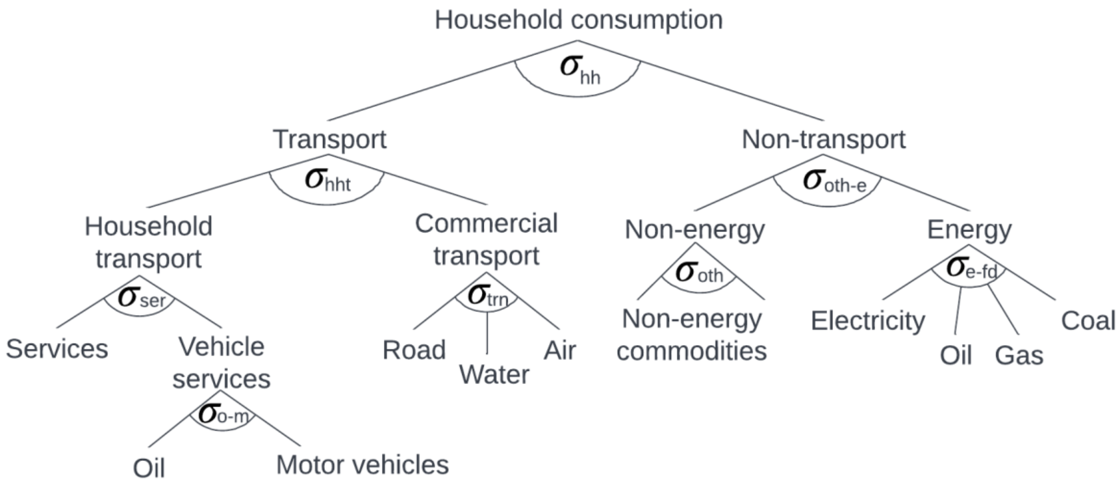

Figure 4. Household consumption nest. Subscripts represent different substitution levels (σ): *hh* between transport and non-transport composites, *hht* between household and commercial transport composites, *ser* between service composites, *o-m* between oil and motor vehicle services, *trn* between commercial transport alternatives, *oth-e* between energy and non-energy composites, *oth* between non-energy commodities, and *e-fd* between energy sources.

2.3 Sectoral representation

The 36 representative sectors included in this study, listed in Table 1 with their respective codes, are based on the 38 sectors included in Winchester and White (2022). The list is comprehensive enough to represent relevant sectors in both Auckland region and the rest of New Zealand by including six primary industries, 11 manufacturing sectors, 12 energy sectors, 1 representative construction sector, 2 service sectors (including waste management)[2], and 6 transport sectors (5 commercial alternatives and 1 for households). Besides the inter-sectoral demand of intermediate inputs, the model also includes the final demand/consumption of commodities by households, government, and investment. Industry aggregation, disaggregation, and mapping processes concorded the list of commodities and sectors included in the original supply-use tables published by Statistics New Zealand with the original C-PLAN study. We describe this in detail in the benchmark calibration section.

Table 1. Sectors considered in the CGE model for both Auckland and the Rest of New Zealand

Code	Sectors	Code	Sectors
rmk	Dairy Farming	nmm	Non-Metallic Minerals (e.g., Cement)
bas	Beef and Sheep Farming	nfm	Iron, Steel and Non-Ferrous Metals
oap	Other Animal Products	fmp	Fabricated Metal Products
hor	Horticulture	mil	Dairy Processing

[2] The assumption from the original C-PLAN study is that 35% of waste CH_4 emissions were generated by managed landfills in 2014.

frs	Forestry	mtp	Meat Products
fsh	Fishing	ofd	Other Food Products
col	Coal Mining	wpp	Wood And Paper Products
cru	Crude Oil Extraction	mvh	Motor Vehicle and Parts
gas	Gas Extraction and Distribution	omf	Other Manufacturing
oil	Refined Oil Products	cns	Construction
oxt	Other Mining	afs	Accommodation and Food Services
eco	Coal Electricity	ser	Other Services
ega	Gas Electricity	rtp	Road Transport
ehy	Hydro Electricity	wtp	Water Transport - Domestic
ews	Wind and Solar Electricity	atp	Air Transport - Domestic
eot	Geothermal Electricity	wtpi	Water Transport - International
tnd	Electricity Trans and Distribution	atpi	Air Transport - International
crp	Chemical, Rubber and Plastic Products	hht	Household Transport

2.4 Dynamic process

The model is a recursive dynamic CGE model with commodity/factor prices, labour supply and capital formation, in each time step, dependent on value of the corresponding variables in the previous time step as depicted in Figure 5, i.e., myopic foresight by the agents. The set of parameters that change through time are capital (fixed and mobile), labour (force and productivity), Autonomous Energy Efficiency Improvements (AEEI), autonomous GHG emissions reduction, caps on GHG emissions, and various other resource endowments (e.g., land and TSFs).

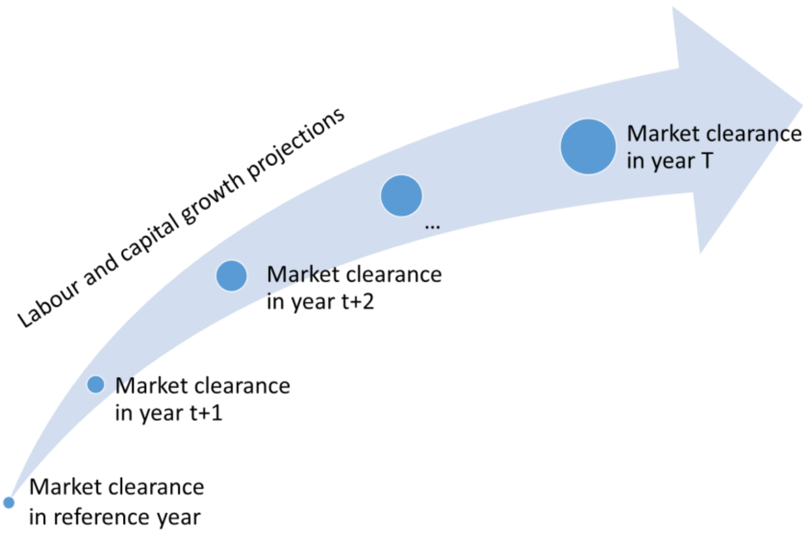

Figure 5. Graphical representation of the recursive dynamic structure using labour and capital growth projections

2.4.1 Benchmark capital calibration

Before discussing the capital growth component of the model, benchmark capital earnings are first recalibrated to be consistent with capital stocks. Based on previous literature on recursive dynamic CGEs (Klepper et al., 2003; Paltsev et al., 2005; Rutherford, 1999), initial capital stocks (*ks*) are first estimated based on benchmark investment (inv^0) as the latter is a more accurate figure than national/regional capital stock accounting.[3] As show in equation 1, capital stocks are estimated using a classical growth relationship where current capital stocks are a function of investment, capital growth rate (*grow*) and depreciation (*dep*) in the two different regions (*r*).[4] As show in equation 2, capital stocks are then converted to earnings/payments (*ke_t*) based on the assumption that the ratio of capital earnings-to-stock is equal to the rate of return (*ror*), defined as the sum of the rates of interest (*int*) and depreciation (*dep*) (Paltsev et al., 2005). The new capital earnings estimate is applied to recalibrate benchmark (ke_s^0) capital earnings/payments employed in each sector (*ke_s'*) as shown in equation 3 (TF Rutherford, 1999).

$$ks_r = \sum_c inv^0_{c,r} / (grow_r + dep) \tag{1}$$

$$ke\_t_r = ks_r * ror \quad \text{where} \quad ror = int_r + dep \tag{2}$$

$$ke\_s'_{a,r} = ke\_t_r * \left(ke\_s^0_{a,r} / \sum_a ke\_s^0_{a,r} \right) \tag{3}$$

Capital is fixed (ke_s^{fix}) or mobile (ke_s^{mob}). Fixed capital is sector specific and can only be applied in the sector where it is currently employed. Mobile capital can be used in any sector. The explicit specification of fixed (or non-malleable) capital incorporates into the model a more realistic level of sectoral rigidity (or inertia) to the adjustment (or retrofitting) of existing technologies to comply with limiting GHG caps (Jacoby and Wing, 1999).[5] According to Rutherford (1999), benchmark mobile capital is estimated according to equations 4.[6] Benchmark fixed capital is the balance from total capital payments in each sector after subtracting mobile capital as shown in equation 5.

$$ke\_s^{mob}_{a,r} = [ke\_s'_{a,r} * (dep + grow_r)] / (1 + grow_r) \tag{4}$$

$$ke\_s^{fix}_{a,r} = ke\_s'_{a,r} - ke^{mob}_{a,r} \tag{5}$$

2.4.2 Capital growth

The evolution of the capital endowments over time is implemented in the following set of dynamic equations. According to Rutherford (1999) and Winchester and White (2022), solution investment levels in every period become the new mobile capital (ke_t^{mob}) in period t+1 as shown in equation 6. New mobile capital is then allocated across sectors (ke_s^{mob}) using a Constant Elasticity of Transformation (CET) nest with a Leontief structure (i.e., fixed proportions). Once allocated to different sectors, the new capital is

---

[3] Generally, national capital stock accounting results in significantly different capital-output ratios from observed ranges (Paltsev et al., 2005 page 26; Klepper et al., 2003).

[4] The original, simple equation would be 'change in capital stock' = investment – (depreciation rate x capital stock). Dividing everything by capital stock would result in equation 1.

[5] This specification avoids the potential instantaneous movement of capital into new low-emissions technologies which could result in high abatement costs in the short run under the assumptions of myopic foresight (or short-run optimisation by agents) and fully mobile capital. Both being conventional assumptions used in the CGE modelling literature.

[6] This estimation is based on equation 6. Integrating equations 1 and 2 into 4, and summing over sectors, would result in a similar dynamic relationship to equation 6.

then depreciated along with the current year's fixed capital to form next year's endowment of fixed capital to be used in the various production functions as shown in equation 7. The updated supply of each capital type is used as an exogenous shock and the capital rental rates are endogenously determined in each period.

$$ke\_t^{mob}_{r,t+1} = inv_t * ror \quad (6)$$

$$ke\_s^{fix}_{a,r,t+1} = \left(ke\_s^{fix}_{a,r,t} + ke\_s^{mob}_{a,r,t}\right) * (1 - dep) \quad (7)$$

2.4.3 Labour growth

Following CGE modelling convention, the labour endowment (*lab*) updates in every period using an exogenously determined growth rate (*lgrow*) as show in equation 8. The growth rate of the labour endowment is a function of labour force (*lfg*) and productivity (*lpg*) growth rates as shown in equation 9. The growth of the labour force links to population growth in both regions. Labour is perfectly mobile across sectors and regions and, following an assumption of full employment, the national wage adjusts to clear labour markets every period.

$$lab_{r,t+1} = lab_{r,t} * (1 + lgrow_{r,t}) \quad (8)$$

$$lgrow_{r,t} = lfg_{r,t} + lpg_{r,t} + (lfg_{r,t} * lpg_{r,t}) \quad (9)$$

2.4.4 Other exogenous time series

The other exogenous time series that drive the dynamic component of the model are AEEIs, resource endowments, autonomous GHG emissions reductions and the GHG caps – see the next section. Like Paltsev et al. (2005) and Winchester and White (2022), AEEIs represent energy efficiency improvements as scaling factors that reduce the energy inputs required per unit of output in non-energy sectors. The growth trends of certain resource endowments (e.g., land and TSFs) are also used to control the output from certain industries to follow exogenously modelled forecasts (e.g., electricity sectors with TSFs), to integrate the impact from environmental policies (e.g., water policies through land endowments), and to account for the gradual closure of emission-intensive plants (e.g., closure of Tiwai point) over time.

2.4.5 Closure

Following Winchester and White (2022), in every solve period, the current account balance is fixed to benchmark values. Government spending is endogenously determined as a function of endogenous tax revenues net of transfers. Investment spending is also endogenously determined as a function of households and government savings net of the current account balance.

2.5 GHG markets

As shown in Figure 6, GHG emissions in the model are linked to two potential sources (bold font in the figure): (1) the combustion of fossil fuels (i.e., CO_2 from coal, gas, and refined oil) and (2) non-combustion

GHGs (i.e., process-based CO_2, CH_4, N_2O and F-gases). Table 2 lists the total combustion and non-combustion GHGs emitted per sector in New Zealand in 2014 in million tonnes CO_2e obtained from New Zealand's GHG Inventory 1990-2017 (Ministry for the Environment, 2019a).[7] As shown on the lower right-hand corner of Figure 6, the rate at which CO_2 emissions are generated from the consumption of each type of fossil fuel is constant (i.e., perpendicular lines representing a Leontief structure). Hence, producing sectors can reduce GHG emissions by substituting fossil fuels for less carbon intensive sources of energy (i.e., renewable electricity and dictated by σ_{ene}) and/or more capital-labour inputs (i.e., energy-efficient technologies and dictated by σ_{e-f}). As shown on the upper right-hand corner of Figure 6, process-based non-CO_2 emissions (measured in CO_2 equivalent units) are generated at different rates depending on the price signals. If there is a price on non-CO_2 emissions, producing sectors can substitute the cost of emissions for all other inputs (Chen et al., 2016; Winchester and White, 2022). The model also integrates autonomous emissions reductions for the non-combustion GHGs in the baseline and policy scenarios to reflect the inertia gained from existing efforts to reduce emissions by various sectors, e.g., more efficient feed utilisation by the dairy industry.

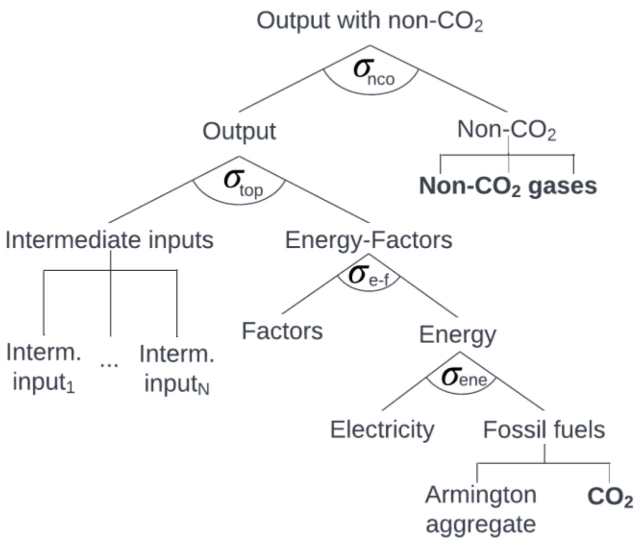

Figure 6. Generic production nest with combustion (CO_2) and non-combustion (non-CO_2) GHG emissions

[7] Refer to Winchester and White (2020) for a detailed description on mapping sectors from NZ's GHG Inventory to C-PLAN.

Table 2. Gross GHG emitted by the sectors included in the CGE model in 2014 (million tonnes CO_2e)

Sectors	**Combustion CO_2**			**Non-combustion GHGs**			
	Coal	Gas	Oil	CH_4	N_2O	p-CO_2	F-gas
Dairy Farming	0.048	0.002	0.464	15.000	3.192	0.583	
Beef and Sheep Farming	0.059	0.004	0.336	14.403	1.892	0.401	
Road Transport	0.001	0.044	6.656	0.007	0.055		
Household Transport			6.349		0.092		
Other Services	0.104	0.272	0.304	4.070	0.119		
Gas Electricity		3.022		0.002			
Iron, Steel and Non-Ferrous Metals	0.037	0.182	0.095	0.000	0.000	2.271	0.073
Air Transport - International			2.575	0.000	0.021		
Horticulture	0.004	0.003	0.222	0.022	1.858	0.097	
Dairy Processing	1.209	0.554	0.099	0.003	0.005		
Chemical, Rubber and Plastic Products	0.028	1.303	0.096	0.127	0.001	0.254	
Other Manufacturing	0.021	0.037	0.093	0.000	0.058	0.041	1.320
Gas Extraction and Distribution		0.638	0.000	0.402	0.000	0.298	
Non-Metallic Minerals (e.g., Cement)	0.337	0.067	0.044			0.831	
Coal Electricity	1.214				0.007		
Water Transport - International			0.927	0.002	0.008		
Refined Oil Products		0.111	0.768	0.000	0.001		
Air Transport - Domestic		0.000	0.846	0.000	0.007		
Geothermal Electricity				0.166		0.646	
Other Animal Products	0.010	0.001	0.062	0.666	0.019	0.018	
Wood And Paper Products	0.050	0.334	0.074	0.031	0.049		
Households	0.026	0.276	0.064	0.075	0.092		
Other Mining	0.002	0.027	0.481	0.001	0.007		
Other Food Products	0.115	0.263	0.013	0.001	0.002		
Construction	0.002	0.022	0.351	0.001	0.002		
Crude Oil Extraction		0.064	0.000	0.005		0.308	
Fabricated Metal Products	0.005	0.017	0.020	0.000	0.001	0.320	
Meat Products	0.334	0.014	0.004	0.001	0.001		
Coal Mining	0.118	0.000	0.000	0.225			
Water Transport - Domestic	0.001	0.000	0.319	0.001	0.002		
Fishing	0.004	0.145	0.170	0.000	0.001		
Forestry	0.020	0.035	0.144	0.014		0.004	
Accommodation and Food Services	0.003	0.088	0.028				
Motor Vehicle and Parts	0.001	0.000	0.005				
Electricity Trans and Distribution			0.000				

An Emissions Trading Scheme (ETS) is an economic approach to mitigate the effects of climate change by incentivising the reduction of GHG emissions through a price signal. Producers and consumers buy permits to emit GHGs from their processes and actions. The number of permits available for purchase are determined by an ETS cap, which is based on specific GHG reduction goals. As previously mentioned, the Zero Carbon Act lists goals for two different GHG groups by 2050: (1) 24-47% reduction of gross biogenic methane (i.e., CH_4) emissions and (2) net zero emissions for all other GHGs.[8] The two caps change over time to reach the goal by 2050. Hence, for the counterfactual/policy scenario, the model considers two different ETSs covering the two groups. Following mixed complementarity notation as shown in equation 10 and considering two ETSs (*ets*), if more emissions result than that permitted by the caps (i.e., binding caps) in the two different regions (*r*) at a specific period (*t*), the model generates prices (*cprice*) on permits (i.e., shadow value) for the two different GHG groups. If the cap is not binding, then the prices of GHG permits are zero. The permit price is the same for both Auckland region and the rest of New Zealand but different for different caps.

$$\sum_{a} emissions_{a,ets,r,t} \geq cap_{ets,r,t} \perp cprice_{ets,t} \qquad (10)$$

The model also allows for the allocation of free output-based emissions permits for sectors that are emissions-intensive and trade-exposed (EITE) for a certain period.[9] This is in recognition that the ETS restrictions might affect the international competitiveness of businesses in the short term (Ministry for the Environment, 2022). Hence, these EITE sectors receive free permits while they adapt to the decreasing GHG caps. These output-based allocations are joint production of commodities (with respective emissions) and GHG permits as a proportion (β) of the emissions generated by EITE sectors per unit of output in the benchmark ($emissions^0$). Hence, as shown in equation 11, EITE sectors receive a subsidy, which results in a higher consumption of the commodities produced by the EITE sectors. The proportion of the free permits reduces over time (*t*).

$$subsidy_{a,r,t} = \sum_{ets} \beta_{a,ets,r,t} * emissions^{0}_{a,ets,r} * cprice_{ets} \qquad (11)$$

2.6 Advanced and emergent technologies

Advanced technologies are considered in the model as low-emissions alternatives to conventional technologies that will be highly impacted by carbon prices. As listed in Figure 7, the technologies considered are: (1) electric vehicles (EV) for the road and household transport sectors, (2) a methane-reducing technology for the dairy and sheep and beef farming sectors, (3) geothermal electricity with carbon capture and storage (CCS), and (4) electric and bioheat for sectors that heavily depend on industrial heating with coal and gas. Figure 7 also shows the years when each technology becomes available within the time horizon considered in the model, i.e., 2014-2050 period. None of the technologies are operational in the

[8] The difference between gross and net emissions is that the latter includes the removals from forests. Other GHGs include CO_2, N_2O and F-gases.

[9] EITE sectors are dairy processing; meat processing; horticulture; refined oil products; chemical, rubber and plastic products; non-metallic minerals; non-ferrous metals; and wood and paper products.

2014 benchmark and only electric vehicles are present in both the baseline and policy scenarios, the rest are only present in the policy scenario.

When operational, the output from advanced technologies replaces the existing output from conventional technologies (e.g., electric fleets replacing internal-combustion fleets in the road transport sector) or inputs used by conventional technologies (e.g., electric heat replacing the coal-gas aggregate used to dry milk into powder in the dairy processing sector). The operation and deployment of advanced technologies is a function of cost markups and the use of the TSFs as shown in the nesting structures in Figure 8 and Figure 9 in bold fonts. Cost markups represent the currently higher costs of the advanced technologies compared to the conventional ones. As the cost of the conventional technologies increase, due to increasing carbon prices, advanced technologies with their lower GHG footprint become more affordable. As previously mentioned, TSFs control the output from specific sectors. Within this context, TSFs control the deployment and/or market penetration of the advanced technologies.

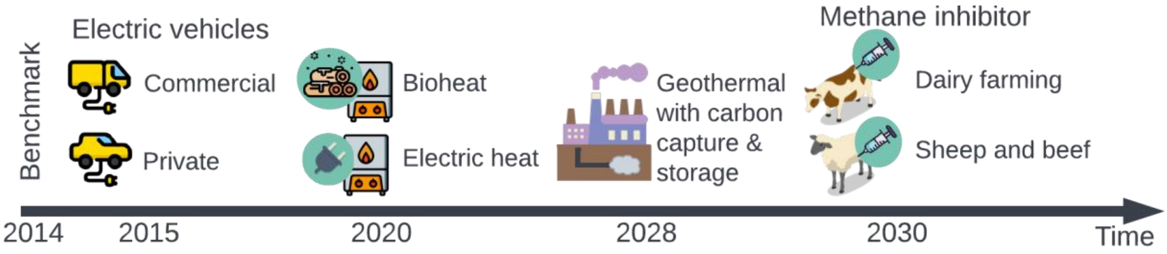

Figure 7. Availability timeline of advanced technologies

The nesting structure for the production of electric road and household transport are shown in Figure 8a and Figure 8b, respectively. The top-level nests include TSFs, which follow exogenous EV deployment projections from the Energy and Emissions in New Zealand (ENZ) model (Concept Consulting, 2021).[10] A positive substitution elasticity in the top nest ($\sigma_{top} > 0$) implies that output from this technology can increase beyond that allowed by the TSF endowment but at a higher marginal cost. Electricity is the only source of energy for both production functions. Factors of production and intermediate inputs for commercial road transport whereas only services and motor vehicles are required for household transport (as per internal combustion engines on the lower left-hand corner of Figure 4). Factors and non-energy inputs have a cost markup. [11] Electricity costs are assigned based on estimates of electricity requirements per vehicle travel kilometres from the ENZ model.[12]

[10] Benchmark TSFs are estimated as a share (5%) of total costs on a per unit basis for both technologies.

[11] The cost markups for EVs used for household transport is 0.75. The markup for EVs used in commercial road transport starts at 0.75 and drops by 1% on an annual basis. All obtained from consultations with CCC experts.

[12] A ratio of the value of electricity-to-oil purchases (considering a constant output from both EVs and internal combustion engines) is used to estimate required electricity costs.

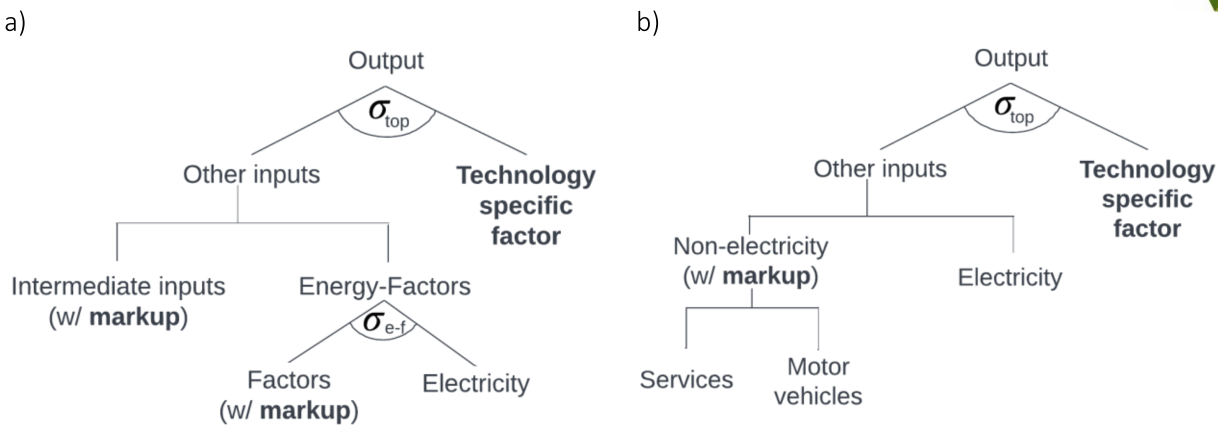

Figure 8. Production nests for electric transport in the: a) road transport and b) household transport sectors. Inputs with a cost markup and the technology-specific factor in bold font

Methane-reducing technologies for the dairy, sheep and beef farming sectors are integrated in the model as additional production functions with nesting structures like their conventional counterparts with the addition of a TSF, cost markups[13] (as shown in Figure 9a) and lower methane emissions. As depicted on the left-hand side of Figure 9a, TSFs are included in a series of Leontief nests with other inputs and a land resource/factor. Since TSFs dictate the maximum production allowed due to the "rigidity" imposed by the Leontief nests through fixed proportions, the deployment of the technology is increased by increasing the TSF proportionally over time. Considering that the GHG footprint of the methane-reducing technology decreases over time and the cost (including the markup) is fixed, the cost of every tonne of CO_2e abated decreases as well hence lowering the permit price for biogenic methane.

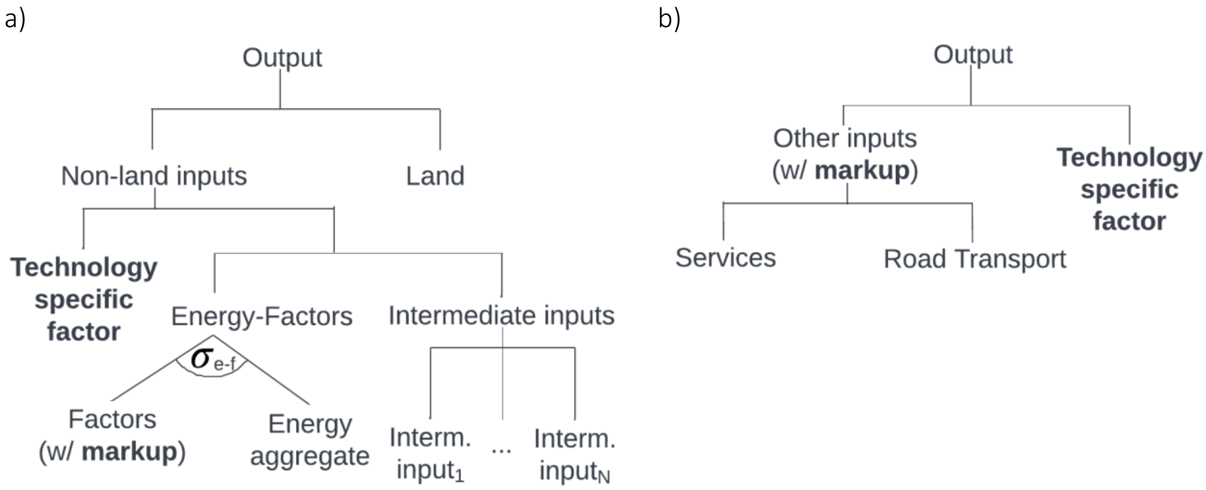

Figure 9. Production nest for: a) dairy, sheep and beef farming with a methane-reducing technology and b) bioheat. Inputs with a cost markup and the technology-specific factor in bold font

Both electric and bioheat are perfect substitutes for the coal-gas aggregate used as an energy input going into the horticulture, dairy processing, meat products, other food products, wood and paper products, and other manufacturing sectors. The bioheat technology's main input is forest residue and its supply is controlled through a TSF endowment (i.e., a function of forest residue availability) as depicted in Figure 9b.

[13] The cost markups for the methane-reducing technology used in dairy farming, and beef and sheep farming are 1.022 and 1.039, respectively. All obtained from consultations with CCC experts.

Bioheat also uses services and transport inputs (with a cost markup[14]) to collect and process the forest residues. The Leontief structure between the TSF and other inputs limit the output of bioheat to the supply forest residues.

The nesting structure of the geothermal electricity sector with CCS is also like its conventional counterpart as depicted in Figure 3 with an additional cost markup for the factors of production.[15] The addition of CCS is like "retrofitting" the existing infrastructure of the conventional technology. Hence, the TSF of the conventional technology can also be used for the new technology, i.e., based on the same exogenous generation projections. However, the fixed sector-specific capital cannot move between the two technologies.

2.7 Green employment

Auckland Council has previously used two definitions for 'Green jobs' (Tuatagaloa, 2014), the first of which being "jobs that produce goods and services that benefit the environment or conserve natural resources using sustainable, environmentally friendly, processes and technologies. (Hancock, 2010)." This report uses the second from Murray (2008) who "looked at each of the six key areas considering the Auckland region economy and the potential/opportunities for green jobs in these areas. Based on this analysis, the proportions of Auckland region's economy that make up the green industry were then coded according to industry classification, and each Australian and New Zealand Standard Industry Classification (ANZSIC) 96 six-digit code weighted to reflect the proportion of that industry assumed to be involved in the green sector."

This report adapts the definition of Murray (2008) to the CGE model industry definitions (see Appendix 3). The new industries defined in the CGE analysis are assumed to all be wholly involved in the green sector. A concordance that maps these industry definitions to the ANZSCO 2-digit occupation definitions is then applied to convert employment numbers categorised by industry generated by the CGE model to employment numbers by industry and occupation type. Employment numbers are reported as Modified Employment Counts (MECs), a metric that combines Statistics NZ's employment count and working proprietor data that represents the total number of workers in each business. This analysis is also used to calculate job losses associated with the winding down of traditional industries and the transition away from traditional technologies to new green technologies.

2.8 Scenarios

This section describes the calibration of the benchmark year and the development of the baseline and policy scenarios in detail. For the benchmark calibration and the development of the baseline scenario, data was used from the original study for the whole of New Zealand (Winchester and White, 2022) and new data was developed for the specific case of Auckland region. The baseline and policy scenarios follow the "Current Policy Reference" and the "Target Pathway 2" scenarios used in the CCC's draft advice to

[14] The bioheat markup (1.67) is based on a cost of biomass supply of $10 per gigajoule (GJ) and a cost of energy from coal-gas of $6 per GJ.

[15] The markup of 1.21 is estimated as the value of emissions relative to the value of production under the conventional technology assuming that the CCS technology will be profitable at a carbon price of $150/tonne (Winchester and White, 2022).

government on climate action (Climate Change Commission, 2021b). With the help of key Auckland Council staff, a new policy scenario was developed by modifying certain assumptions used in the original study by the CCC and tailored for the specific case of Auckland region as listed in Table 3 and described in sub-section 2.8.4.

Table 3. List of scenarios assessed

	Baseline	Policy	Auckland
GHG caps			
Auckland	No caps	CCC's Target Pathway 2	Te Tāruke-ā-Tāwhiri
Rest of New Zealand	No caps	CCC's Target Pathway 2	CCC's Target Pathway 2
Iron and steel output			
Auckland	Constant	Constant	Variable*
Rest of New Zealand	Constant	Constant	Constant*

*In both alternative baseline and policy scenarios for Auckland region.

2.8.1 Benchmark

The model uses as its main inputs two inter-related SAMs: one for Auckland region and one for the rest of New Zealand. The SAMs were developed using the procedure described in Smith et al. (2015). The procedure first generates a national SAM using as its main inputs: the national supply-use tables (NZSUT) and the institutional sector accounts published by Statistics New Zealand for the period 2006-07. The Auckland regional SAM was developed from the national SAM using ancillary data such as: Statistics New Zealand's 2006 census of population and dwellings, the household economic survey, regional GDP series, sub-national population projections, income survey as well as the Ministry of Business, Innovation & Employment's domestic tourism survey and regional tourism estimates. The SAMs used date back to 2007 and were updated to 2014 using the dynamic procedure previously described to comply with the original study's benchmark year of 2014.

Given that the SAMs used in Winchester and White (2022) were different to the ones used in this study; industry aggregation, disaggregation and mapping processes were required to match the list of industries considered in the original C-PLAN study. Sectoral aggregation was required as the original NZSUT contained 205 commodities and 106 sectors. The common denominator among the two different datasets was the GTAP dataset. Hence, the C-PLAN-to-GTAP map listed in the supplementary material of Winchester and White (2022) was used as well as the NZSUT-to-GTAP map provided by (Strutt, 2021). The final concordance table used is listed in Appendix 1. The supply submatrix of the inter-related SAMs was diagonalised (i.e., from one-to-many to one-to-one) to comply with the original study's SAM structure following a procedure developed by Rutherford (2004).

Since the version of GTAP used in C-PLAN (i.e., GTAP-Power) has a more detailed representation of electricity generation and transmission, the aggregate electricity sector in the regional SAMs was separated first into generation and transmission using the original shares of electricity transmission from the NZSUT. The aggregate electricity generation sector was then separated into electricity generation from coal, gas, hydro, solar/wind, and geothermal using the benchmark shares of total generation considered in the original C-PLAN study for both the Auckland region and the rest of New Zealand.[16] All of the coal and gas

[16] Additional sectoral aggregation/disaggregation included C-PLAN's iron and steel and non-ferrous metal sectors aggregated into one, disaggregation of crude and gas from NZSUT's crude extraction sector (including gas) using the supply shares of separate crude and gas commodities.

inputs used by the original aggregate electricity sector were reallocated to the new separate coal and gas electricity sectors, respectively. The same procedures used by Winchester and White (2022) were followed to separate domestic and international aviation and marine transport as well as household transport from the consumption of transport by households.

Complying with the same benchmark emissions data used in the original C-PLAN study, the emissions per sector listed in Table 2 were used. As shown in equations 12 and 13, the benchmark non-combustion (*nco2*) and combustion (*co2*) GHG emissions (*t_emiss*) listed in Table 2 along with the benchmark supply ($make^0$) and use (use^0) sub-matrices (summed across regions *r*) were used to obtain national emission intensities (*emiss_int*) for every producing sector (*a*) and consumption agent (*d* is a superset of *a* including households). As shown in equations 14 and 15, the national emission intensities where then allocated to the different regions (*r*) using the regional supply and use sub-matrices.

$$emiss\_int^0_{nco2,a} = t\_emiss^0_{nco2,a} / \sum_r make^0_{a,r} \tag{12}$$

$$emiss\_int^0_{co2,d} = t\_emiss^0_{co2,d} / \sum_r use^0_{co2,d,r} \tag{13}$$

$$emissions^0_{nco2,a,r} = emiss\_int^0_{nco2,a} * make^0_{a,r} \tag{14}$$

$$emissions^0_{co2,d,r} = emiss\_int^0_{co2,d} * use^0_{co2,d,r} \tag{15}$$

The same elasticities of substitution were used as in the C-PLAN study and reported in Winchester and White (2022). These elasticities were derived mainly from two sources: the MIT-EPPA model (Paltsev et al., 2005) and the GTAP Database (Burniaux and Truong, 2002).

2.8.2 Baseline

By convention with dynamic CGE models, a baseline scenario is generated with future economic projections consistent with observed behaviour (i.e., benchmark calibration) and expected future changes (i.e., socioeconomic drivers integrated as multipliers). The baseline scenario is then used as a reference to evaluate the policies in question included in the policy scenarios. While the procedures characterising the dynamics of factor endowments (i.e., labour and capital) was described in section 2.4, this section will outline the data used in such procedures as well as other relevant drivers expected to impact future GHG emissions and sectoral output (both endogenous in the baseline) such as electricity generation, resource constraints, and expected technology developments.

Since most of the drivers are projected using multipliers in the model, the same projections have been used for both the Auckland region and the rest of New Zealand, each based on different benchmark information. While this section will describe what nationwide multipliers were used in the original CCC study and how they were used to represent both the Auckland region and the rest of New Zealand, subsection 2.8.4 will describe how certain assumptions were modified to represent more closely Auckland region's expected growth trajectories. When the drivers are not multipliers but absolute values, the best information in the literature, and provided by key Auckland Council staff, have been used to closely represent expected and planned future trajectories for the Auckland region.

Most of the relevant projections used in the original CCC study are based on the central assumptions from New Zealand's Fourth Biennial Report Under the United Nations Framework Convention on Climate Change (Ministry for the Environment, 2019b) as depicted in the figures in Appendix 2. GPD and labour growth projections are the same for both regions. The deployment of EVs, modelled as the proportion of vehicle travel kilometres by EVs using the TSF, is informed by estimates from the ENZ model and is the same for both regions. For both regions, AEEI multipliers grow annually by 1% for most sectors using fossil fuels except for domestic and international air travel with an annual growth of 1.25% and the electricity sectors with no AEEI. Afforestation projections increase resulting in the removal of 22 million tonnes of CO_2e by 2050. Yield multipliers, reflecting impacts from environmental policies, decrease for dairy by 5% in the 2014-2031 period (to then increase to 2014 levels by 2050), increase for sheep and beef by 19% up to 2050, and increase annually by 1% for other animal products, horticulture, and forestry for both regions. Autonomous decreases in methane emission intensities for dairy, sheep and beef, other animal products, horticulture (same as sheep and beef), and services (waste) for both regions are chosen to match projections from the 4th Biennial Report. Restricted output for certain sectors to reflect regulatory and resource constraints is the same for both regions and divided into three groups: (1) Future output cannot exceed benchmark output (fishing, chemicals, minerals, non-ferrous metals[17], iron and steel, and crude oil), (2) output growth cannot exceed GPD growth (other mining, international air travel and water)[18], and (3) output is guided by exogenous trends (water transport)[19]. LES parameters are assigned so that road, air, and household transport consumption follow projections by the Ministry of Transport (2017) and are the same for both regions. National electricity generation by technology in the baseline follows estimates from the ENZ model (Concept Consulting, 2021). The share of electricity generation for the Auckland region across technologies (5%) has been deduced from the assumption that 95% of the Auckland region's electricity demands are generated outside (Transpower New Zealand, 2018).[20]

2.8.3 Policy

The policy scenario followed is the "Target Pathway 2" scenario used in the CCC's draft advice to government on climate action (Climate Change Commission, 2021b). The main difference between Target Pathway 2 and the rest of the pathways is that this one considers a more ambitious reduction target for biogenic methane. Following the separation of emission targets established by the Zero Carbon Act for different GHG baskets, the policy scenario considers two ETSs:

1. For biogenic methane from dairy, sheep and beef and services (waste) with a 2050 reduction target of 47% below 2017 levels; and
2. For the rest of the GHGs from all sectors with a net zero target by 2050.

Both ETSs start in 2022 and their caps decrease at a constant annual rate (i.e., linear interpolation) from 2022 up to 2049 to reach their respective goals by 2050. The net-zero target for the rest of the GHGs

17 In anticipation of the closure of the Tiwai Point Aluminium Smelter.

18 Emissions from international transport are not included in the model. To prevent unrealistic growth, their output is constrained.

19 Guided by projections from the Ministry of Transport (2017) output grows by a maximum of 30% up to 2050.

20 A potential caveat is that not all the electricity technologies are available/used in Auckland.

implies that the cap on gross emissions is equal to the projected emission removals by forests of 24 million tonnes of CO_2e, i.e., net emissions are equal to gross emissions minus forest removals.

The dairy, sheep and beef sectors receive free allocations of output-based permits based on benchmark CH_4 emissions per unit as explained through equation 11. The permits decrease at a constant annual rate from 96% in 2022 to 32% in 2050 for both regions. The iron and steel sector in the Auckland region also receives free permits that decrease at a constant annual rate from 97% in 2022 to 0% in 2050.

All advanced technologies are only available in this scenario except for EVs, which are available in both baseline and policy scenarios. Since the focus is on the "Target Pathway 2", the ambitious reduction target for biogenic methane is matched with high emissions reduction and deployment assumptions for the methane-reducing technology. Specifically, the methane-reducing technology becomes available in 2030 with an initial reduction efficiency of 30% per unit of output (compared to the conventional dairy, sheep and beef technologies) and increases by 1% annually to achieve a 50% reduction efficiency by 2050 for both dairy, sheep and beef sectors in both regions. In the special case of the dairy sector, the technology becomes available earlier in 2025 with an initial reduction efficiency of 10% and increases annually by 4% to reach the aforementioned efficiency of 30% in 2030. The methane-reducing technology deployment (controlled by TSFs) can reach a maximum of 90% of dairy output and 80% of sheep and beef output once available.

Following the original C-PLAN study's assumptions on land-use change, specifically afforestation, slightly more marginal land is used for native forests. Although neither of the changes in land use are represented in the model (i.e., marginal land and native forests have negligible values in the market), there is a slight increase in forest removal projections from 22 million tonnes in the baseline to 24 million tonnes of CO_2e by 2050 in this scenario. As forest removals set the target for the ETS covering all GHGs (except CH_4), the national forest removal projections have been split in the following manner: 20% for the Auckland region and 80% for the rest of New Zealand.

The rest of the exogenously determined drivers are the same as in the baseline scenario. The endogenous variables in question from the policy scenario are regional GDP, sectoral production, deployment of new technologies and GHG emissions. These will be contrasted to baseline projections and presented in the following results section.

2.8.4 Baseline and policy scenarios with tailored assumptions for the Auckland region

M.E Research engaged with key Auckland Council personnel to modify certain assumptions considered by the CCC in the national assessment to appropriately represent Auckland's regional economy and transition pathways. One of these assumptions revolves around the sectoral growth of the "iron and steel" sector in the Auckland region. The assumption used by the CCC to constrain the output of the "iron and steel" sector to be constant, based on benchmark levels, out to 2050 does not realistically reflect the potential future growth of the NZ Steel plant located in the Auckland region and potential impacts from emissions reduction pathways under a policy scenario. Hence, the output of the "iron and steel" sector in the Auckland region was left unconstrained (i.e., endogenously determined) in the alternative baseline enabling a contrast with the output under the alternative policy scenario.

Furthermore, the cap on all GHGs (except biogenic methane) for the Auckland region was modified to follow more closely the targets established in “Te Tāruke-ā-Tāwhiri: Auckland’s Climate Plan” (Auckland Council, 2020). Compared to the linearly interpolated and decreasing caps considered in the CCC’s “Target Pathway 2” up to 2050, the targets considered in Auckland’s Climate Plan are more ambitious by aiming to reduce GHG emissions by 50% by 2030 and to achieve net zero emission by 2050. Hence, the cap on all GHGs for the Auckland region was modelled as two linearly interpolated segments: 1) from 2022 to 2030 targeting a 50% reduction and 2) from 2031 to 2050 targeting a net zero goal.

3 Results

Table 4 lists the economic indicators that summarise the implications from a national climate mitigation strategy on the Auckland region's economy. The additional results presented in Figure 10 to Figure 16 complement Table 4 by providing more detail. The baseline emissions of both GHG baskets decrease over time due to expected technological advancements as well as regulatory constraints on emissions-intensive sectors. The low baseline emissions combined with the availability of low-emission technologies and the allocation of free permits to agricultural sectors result in relatively minimal impacts on both regions' GDP and welfare estimates from transitioning to a low-emissions economy in the policy scenario. Contrasted to the rest of New Zealand, the impacts on the Auckland region's economy are higher due to the difference in profile emissions (e.g., urban versus rural sectors), fewer low-emissions alternatives (e.g., methane-inhibitors are not critical), and indirect impacts from importing agricultural products with a higher price tag due to rising GHG prices.

Table 4. Economic indicators under different time periods and scenarios

Economic/Environmental Indicator	2015		2050			
			Baseline		Policy	
	Auckland	Rest of NZ	Auckland	Rest of NZ	Auckland	Rest of NZ
GDP (billion 2014 NZ$)	79.4	133.5	150.9	249.7	141.7	246.8
% Change wrt baseline					*-6.1*	*-1.1*
Consumer welfare (billion 2014 NZ$)	54.2	85.6	117.7	194.1	111.7	196.2
% Change wrt baseline					*-5.0*	*1.1*
GHG emissions (million tonnes CO_2e)						
Biogenic methane	2.8	33.1	2.4	30.8	1.9	16.6
All other GHG – gross	13.3	35.5	6.3	28.1	4.7	19.6
Forest removals	4.0	9.3	4.7	19.6	4.7	19.6
All other GHG – net	9.3	26.2	1.6	8.5	0.0	0.0

3.1 Emissions

As depicted in Figure 10, the baseline emissions of both GHG baskets (solid lines) decrease over time in both the Auckland region and the rest of New Zealand. Figure 10a shows that baseline emissions of all other GHGs decrease over time for both regions due to the introduction of electric vehicles, higher autonomous energy efficiency gains and output constraints imposed on emissions-intensive sectors. Considering the forecasted forest removals, net emissions drop more drastically than the gross emissions of all other GHGs. Figure 10b shows that baseline biogenic methane emissions decrease over time due to decreasing GHG intensities and productivity constraints imposed on certain agricultural sectors due to environmental policies.

GHG emissions under the policy scenario decrease linearly (i.e., more restrictive) over time, following the exogenously imposed caps, reaching their respective goals by 2050 as established by the Zero Carbon Act as shown by the dotted lines in Figure 10. Under the policy scenario, gross emissions are 18% and 23% lower than baseline emissions of biogenic methane and of all other GHGs for the Auckland region, respectively. When considering the forecasted forest removals under the policy scenario, the cap on all other GHGs reaches a net zero goal for both regions by 2050. As previously mentioned, approximately 20% of total forest removals (5.6 million tonnes CO_2e) have been allocated to the Auckland region cap on all other GHGs. Along with the decreasing caps, the GHG permits become scarcer and the price generated as a result increases over time, as explained later.

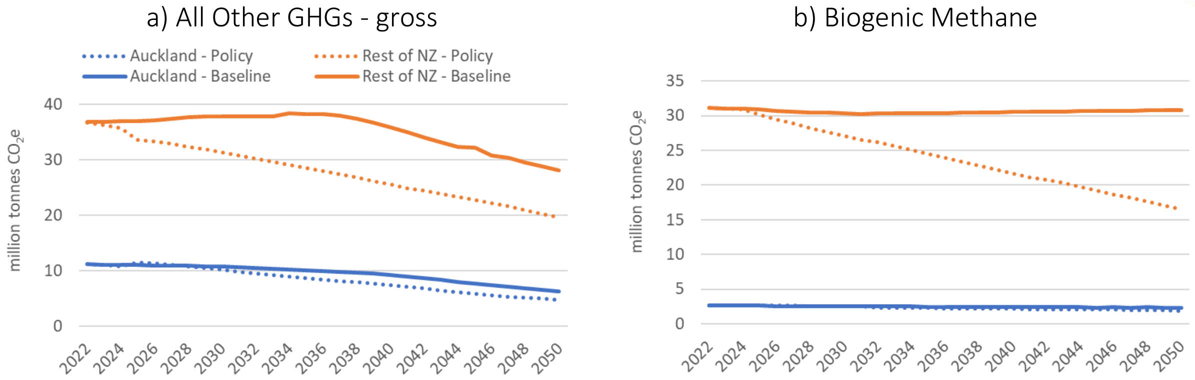

Figure 10. Emissions for two different GHG baskets in the baseline and policy scenarios for Auckland and the rest of New Zealand (million tonnes CO_2e)

Figure 11 shows the different GHG emissions profiles for the Auckland region and the rest of New Zealand and their evolution over time under the two scenarios considered. While over half of the emissions in the rest of New Zealand came from agricultural sectors in 2014, the greatest shares of emissions in the Auckland region came from manufacturing and mining sectors (31%), households' consumption (17%), transport (14%) and services (15%). Over time, baseline emissions decrease across sectors and regions as sectoral output growth has been heavily constrained to follow conservative exogenous growth trends as explained in the section on the baseline scenario. As an exception, the emissions from household consumption and other commercial transport (mainly air transport) are expected to grow as their respective outputs are not constrained to follow exogenous growth trends, i.e., they are endogenously determined and grow according to the baseline growth pattern. Under the policy scenario, the sectors that would experience the greatest emissions reduction would be household transport, road transport and electricity in the Auckland region and agriculture in the rest of New Zealand. The increasing use of EVs is a major driver of emissions reduction in the Auckland region whereas the cap on biogenic methane emissions from agriculture and the availability of methane-reducing technologies would be major drivers of reduction in the rest of New Zealand.

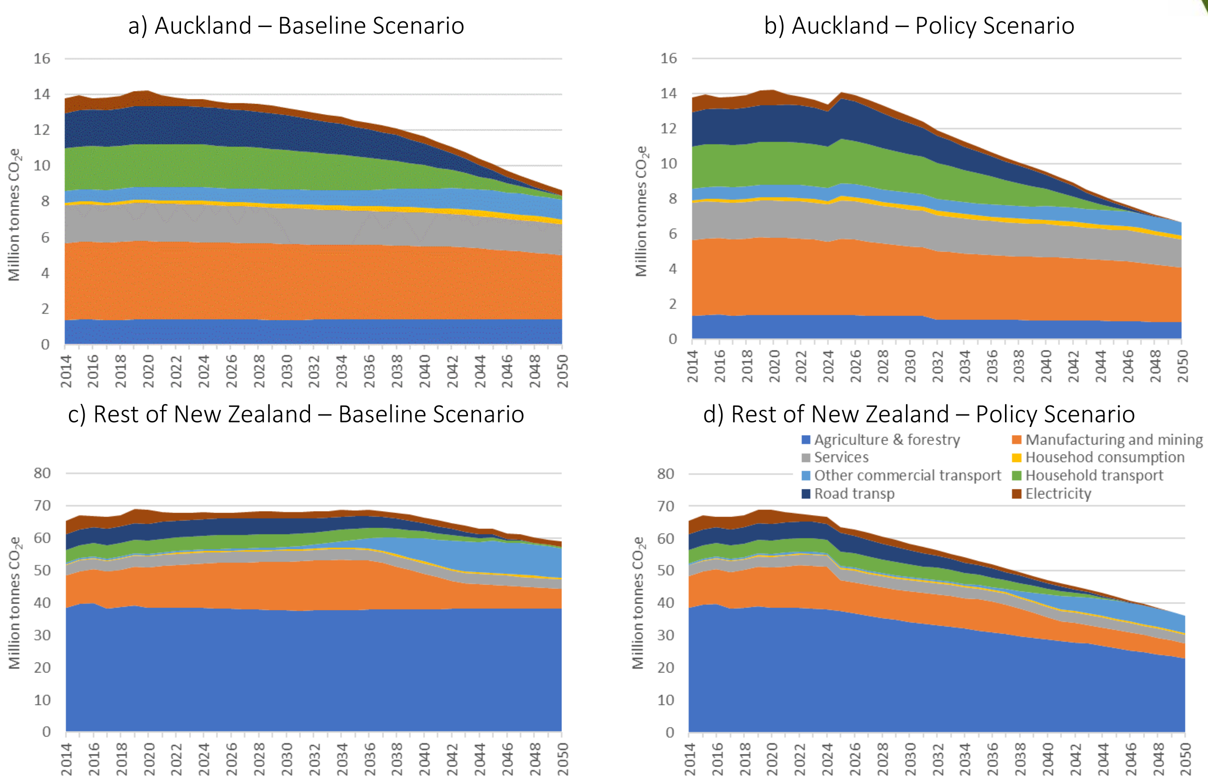

Figure 11. Sectoral gross emissions for Auckland and the rest of New Zealand under both baseline and policy scenarios (million tonnes CO_2e without bunker fuels)

3.2 Price of GHG permits

Figure 12 shows the evolution over time of the permit prices for the GHGs covered in the two ETSs. There is only one permit price for each ETS for both the Auckland region and the rest of New Zealand. Both prices tend to increase due to the decreasing ETS caps over time. Both price series roughly share similar trends with those published by the CCC in the original C-PLAN study.[21] As shown in Figure 12a, the permit price for the ETS covering all other GHGs increases over time reaching a price of approximately \$350/tonne CO_2e in 2050.

As shown in Figure 12b, the permit price on biogenic methane emissions initially increases quite drastically due to the decreasing ETS cap and decreases once the methane-reducing technology is available in 2025 under the policy scenario. The price somewhat stabilises due to the existence of the methane-reducing technology. Once the maximum technological deployment limit is reached (exogenously established at 90% for dairy and 80% for sheep and beef), the price drastically increases. This is a result of the original assumption used by the CCC of exogenously setting maximum deployment limits for the methane-reducing technology. If the deployment was determined endogenously, the high methane permit price would spur additional deployment and/or innovation (Winchester and White, 2022).

[21] Results can be accessed at https://www.climatecommission.govt.nz/get-involved/sharing-our-thinking/data-and-modelling/.

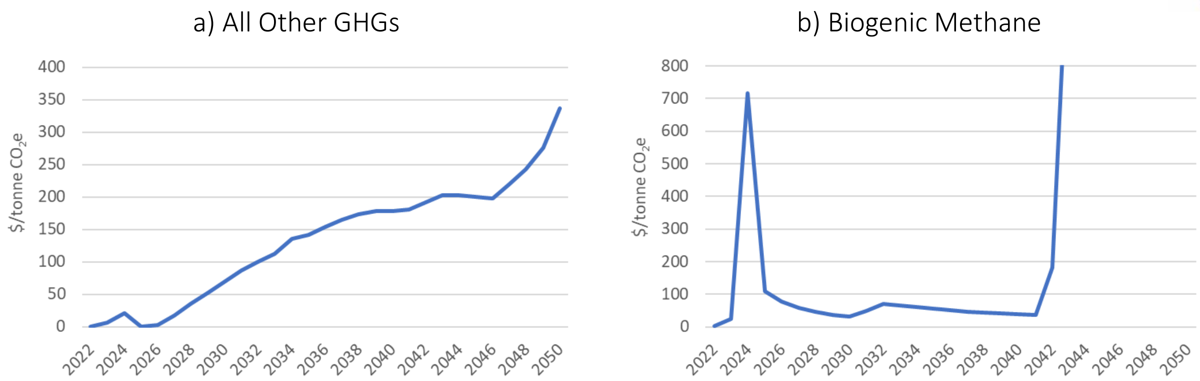

Figure 12. Prices for the GHG permits under two different baskets in the policy scenario ($/tonne CO_2e)

3.3 Sectoral output

Figure 13 shows the change in output (at constant prices) from various primary and manufacturing sectors under the baseline and policy scenarios for the Auckland region and the rest of New Zealand. The change in output was estimated by subtracting the output in 2050 from the one in 2014. This shows a better contrast of the evolution of output over time across scenarios. Figure 13a shows that the ETS caps under the policy scenario predominantly affect the output of the dairy, sheep and beef farming sectors in the rest of New Zealand. The effects in the Auckland region are minimal as primary sectors play a minor role in the region.

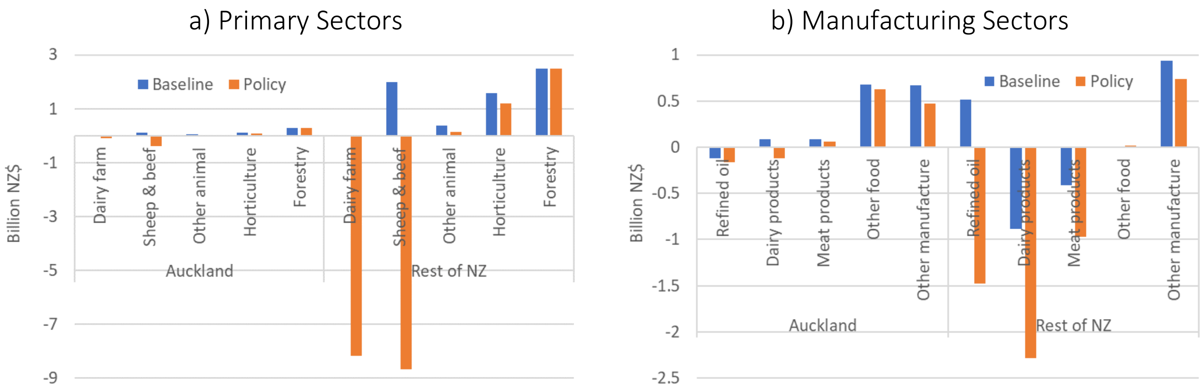

Figure 13. Absolute change in output from various primary and manufacturing sectors in the 2014-2050 period under the baseline and policy scenarios for the Auckland region and the rest of New Zealand (Billion NZ$)

Figure 13b shows that the ETS caps affect mostly the refined oil, dairy products, and meat products sectors in the rest of New Zealand. The latter two are affected due to the reduced output from dairy, sheep and beef farming. Auckland region's manufacturing sectors are all affected by the ETS caps as their respective outputs are lower than their baseline counterparts. The output from refined oil would decrease due to the lower use of internal combustion engines. The output from food manufacturing sectors would decrease due to the reduced imports of products from the dairy, sheep and beef sectors in the rest of New Zealand.

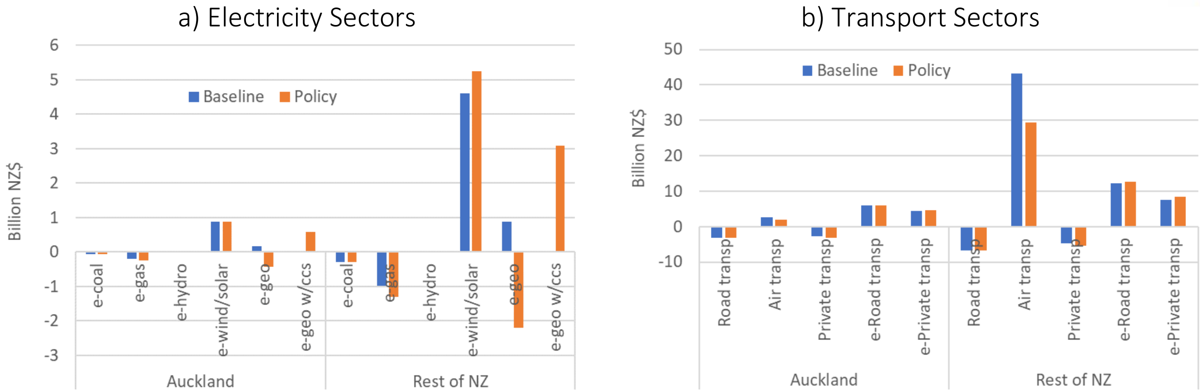

Figure 14. Absolute change in output from various electricity and transport sectors in the 2014-2050 period under the baseline and policy scenarios for the Auckland region and the rest of New Zealand (Billion NZ$)

Figure 14 shows the change in output from electricity and transport sectors for both regions and scenarios. Electricity generation in both regions generally follows the trends projected by the ENZ model with increasing generation from geothermal, wind and solar; constant from hydro; and decreasing from coal and gas over time as shown in Figure 14a. Overall, wind and solar increase more under the policy scenario due to their low-emissions profile. The decreasing output from the conventional geothermal technology is picked up by the new geothermal technology with CCS. The changes are minor in the Auckland region due to the low share of the national generation allocated to the Auckland region (5%). The increasing output from electricity sectors enables a higher integration of EVs under the policy scenario as show in Figure 14b. Overall, the output from the road and private transport sectors, relying on internal combustion engines, decreases and is picked up by the electric road and private transport sectors. The output from air transport increases under both scenarios, but less so under the policy scenario.

3.4 Consumption

Figure 15 shows the absolute change in the consumption of a variety of food products by a representative household in the 2014-2050 period for the Auckland region and the rest of New Zealand. The consumption of dairy and meat products decreases in the Auckland region under the policy scenario. This is a result of the ETS cap on biogenic emissions restricting output from the dairy, sheep and beef farming sectors in the rest of New Zealand, as shown in Figure 13a, and the ensuing import price increase in the Auckland region. As an overarching measure of the impact of the policy scenario on the consumption of the representative households in both regions, consumer welfare decreases in the Auckland region (-5%) and increases in the rest of New Zealand (1.1%) with respect to the baseline as listed in Table 4 and measured using the equivalent variation welfare metric. Equivalent variation represents the change in income, at current prices (i.e., without GHG permit prices), that would have the same effect on consumer welfare as would the change in prices (i.e., with GHG permit prices), with income unchanged. For example, in the case of the Auckland region, consumers would be worse off as the higher prices under the policy scenario (including GHG permit prices) would be equivalent to reducing consumers' incomes by 5% now without the GHG caps and permit prices. Hence, not only are the production sectors affected in the Auckland region but also households consuming the agricultural products produced outside of the Auckland region. This indirect impact is one of the advantages of using a multi-regional CGE to disentangle the regional impacts from national policies.

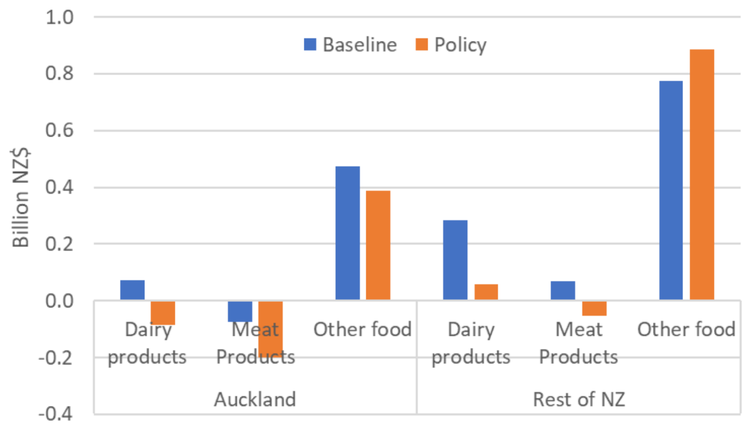

Figure 15. Absolute change in the consumption of various food products by households in the 2014-2050 period under the baseline and policy scenarios for the Auckland region and the rest of New Zealand (Billion NZ$)

3.5 Regional GDP

Figure 16 shows the absolute and relative changes in the GDP of both regions over time under both the baseline and the policy scenarios. In absolute terms, the GDP of both regions grows under both scenarios as shown in Figure 16a. However, in relative terms, the GDP in both regions increases at a lower rate under the policy scenario as shown in Figure 16b in percent changes with respect to the baseline. The Auckland region's economy is affected to a larger extent, compared to the rest of New Zealand, close to the end of the time horizon considered. These results show that while changes in GDP for the whole of New Zealand might be modest, the changes in GDP for certain regions like Auckland are higher than expected due to the different emissions profiles generated by a different set of emissions-intensive sectors.

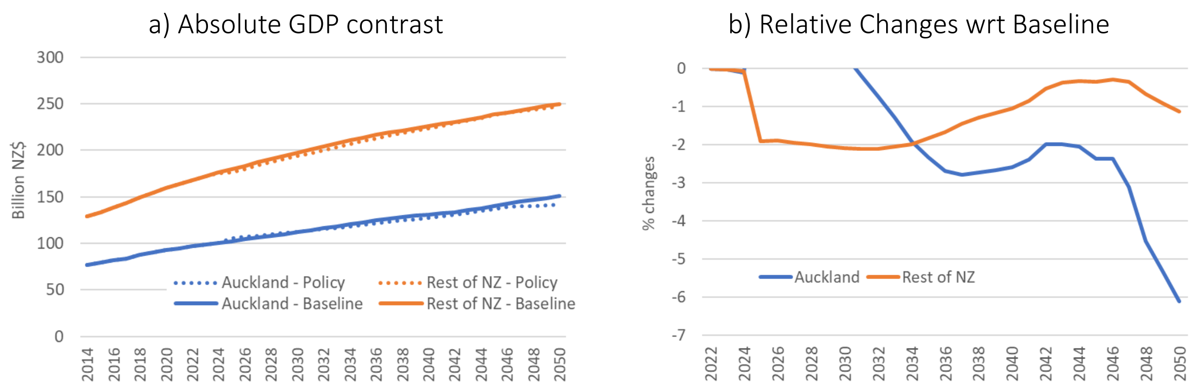

Figure 16. Absolute and relative contrast of regional GDP for the Auckland region and the rest of New Zealand under both baseline and policy scenarios

3.6 Tailored results for the Auckland region

Overall, the results do not change significantly when including the two modifications in the alternative baseline and policy scenarios tailored to the specific Auckland region context. The following section lists the most relevant changes.

As depicted in Figure 17, considering the reduction targets published in "Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan", the price increases more drastically up to 2030 due to Auckland region's more stringent reduction targets by 2030 compared to the price trend under the CCC's Target Pathway 2 scenario. The price difference reaches a maximum of \$60/tonne CO_2e in 2034. Both price trends converge towards 2050 as both scenarios reach a net zero target.

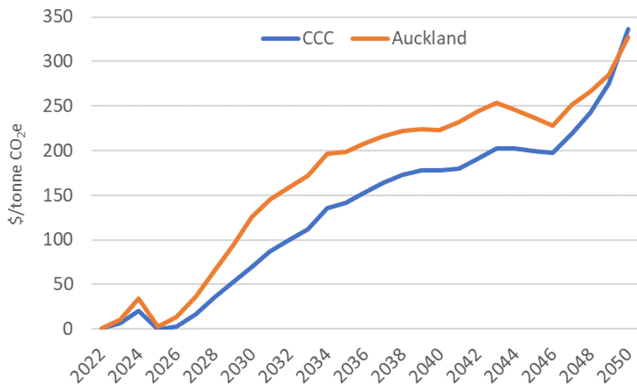

Figure 17. GHG permit prices for the ETS considering all GHGs except biogenic methane under the assumptions followed by the CCC and the ones tailored to the Auckland region (\$/tonne CO_2e)

Over time, baseline emissions are expected to decrease across sectors and regions except for household consumption, other commercial transport (including air), and manufacturing and mining. The emissions from the latter three sectors grow as their outputs are left unconstrained in both alternative baseline and policy scenarios. The emissions from the Auckland region's manufacturing and mining aggregate sector are expected to increase in the baseline in part due to the modified assumption of unconstrained growth of iron and steel sector, which includes the NZ Steel plant. The emissions of the Auckland region's manufacturing and mining aggregate sector decrease by 14% in 2050 under the alternative policy scenario.

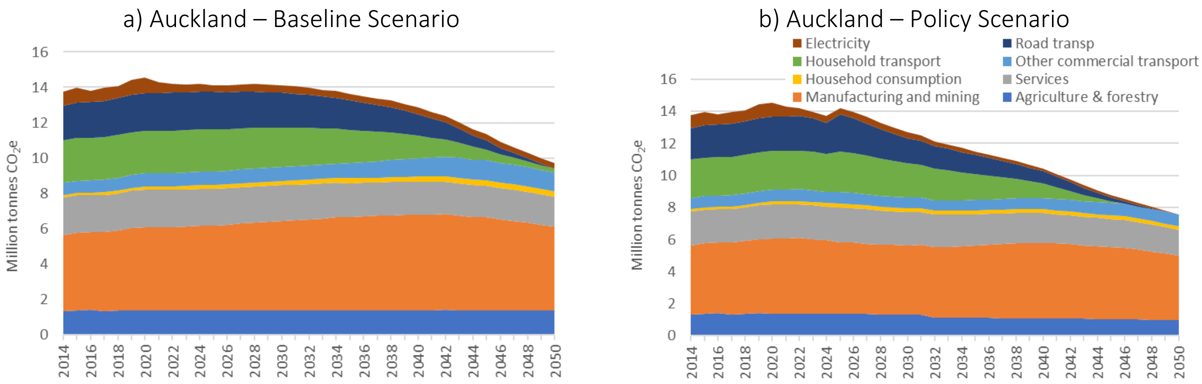

Figure 18. Sectoral gross emissions for the Auckland region under both alternative baseline and policy scenarios tailored for the Auckland region (million tonnes CO2e without bunker fuels)

As depicted in Figure 19, the baseline output of the metal products sector increases in the 2014-2050 period as the growth of the NZ Steel plant is left unconstrained. When contrasted with the alternative policy scenario, the sector's output is reduced by 18% - the highest reduction amongst all sectors in the Auckland region. The sector's output in the rest of New Zealand does not change as it is constrained to maintain benchmark levels as in the original CCC study.

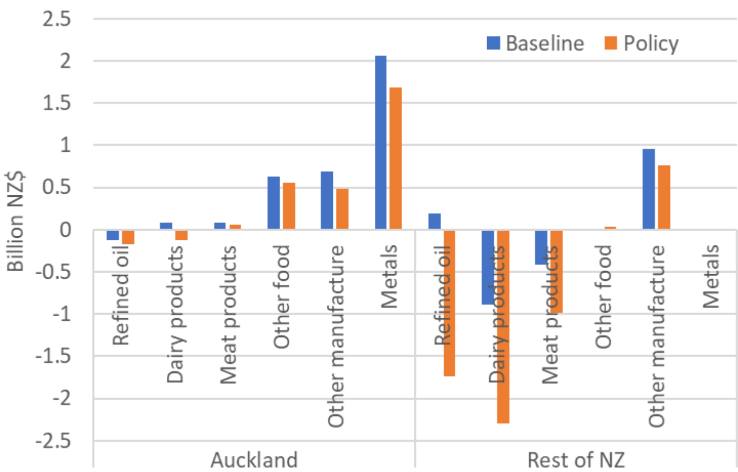

Figure 19. Absolute change in output from various manufacturing sectors in the 2014-2050 period under the alternative Auckland region baseline and policy scenarios for the Auckland region and the rest of NZ (Billion NZ$)

Figure 20 shows the contrast, as percent changes with respect to their respective baselines, of the Auckland region's regional GDP under the CCC's Target Pathway 2 and the more stringent targets considered in the alternative Auckland region scenarios. The differences closely follow the differences of the GHG permit price in Figure 17. Hence, the Auckland region's GDP would be further affected early in the time horizon if the Council decided to enforce the targets published in "Te Tāruke-ā-Tāwhiri: Auckland Climate Plan".

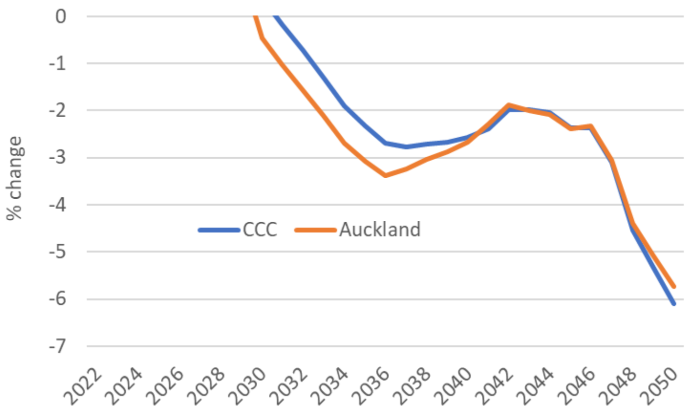

Figure 20. Percent changes with respect to baseline of Auckland's regional GDP under the assumptions originally used by the CCC and the ones developed for the Auckland region

3.7 Employment Impacts

3.7.1 Job Losses

Under the policy scenario, the overall number of job losses (without accounting for transitions to new jobs) by 2050 is 14,800 of 1,540,000 employees (MECs) (approximately 1%). Table 5 presents the job losses for the Auckland region's economy for industries in which net job losses occur. Table 6 presents job losses for selected occupations that are either notable or that are assumed to be the most susceptible to technological changes associated with the transition to a low-emissions economy.

Table 5. Job losses (MECs) for the Auckland region's economy in industries which experience net job losses

	2015	2020	2025	2030	2035	2040	2045	2050
Sheep, beef cattle and grain farming – traditional	52	155	197	233	-983	-975	-966	-952
Dairy cattle farming – traditional	14	-5	-546	-546	-545	-542	-540	-607
Oil and gas extraction - gas	0	2	-1	-1	-2	-2	-2	-5
Electricity generation and supply – coal	-1	-5	-9	-9	-9	-9	-9	-9
Electricity generation and supply – gas	0	1	-1	-1	-1	-1	0	-2
Electricity generation and supply – geothermal	11	13	41	-40	-128	-162	-162	-162
Road transport - traditional	343	2,709	4,060	6,383	6,348	2,696	-6,324	-13,068

Table 6. Job losses (MECs) for the Auckland region's economy selected occupations

	2015	2020	2025	2030	2035	2040	2045	2050
Farmers and Farm Managers	32	69	-220	-201	-739	-739	-745	-786
Specialist Managers	28	191	254	399	337	84	-529	-992
Design, Engineering, Science and Transport Professionals	4	24	37	50	25	-7	-79	-133
Automotive and Engineering Trades Workers	7	56	83	130	119	46	-135	-271
Machine and Stationary Plant Operators	4	26	39	60	46	13	-69	-130
Mobile Plant Operators	6	44	66	103	90	32	-110	-216
Road and Rail Drivers	183	1,438	2,154	3,385	3,356	1,420	-3,362	-6,937
Factory Process Workers	3	19	28	44	38	14	-46	-91

The industry with the largest number of jobs lost by 2050 is traditional (non-EV) road transport (-13,000). Of this -13,000, the largest share are road and rail drivers (-6,900). It is assumed these people can easily transition to driving EVs. Other occupations within the traditional road transport industry that may be more vulnerable to the technology shift to EVs are specialist managers (-888), design, engineering, science and technology professionals (-263), automotive and engineering trades workers (-118), machinery and stationary plant operators (-206), and factory process workers (-87). A comparison of these job losses with those reported in Table 6 shows that most of the losses in these more technically orientated occupations are accounted for by the traditional road transport industry.

The 952 jobs lost for sheep, beef cattle and grain farming, and 607 jobs lost for dairy cattle farming should be able to transition to cattle with methane inhibitors. The job losses for electricity generation from coal, gas, and geothermal (non-CCS) are quite small as the bulk of operation of these industries occurs outside the Auckland region.

3.7.2 Green Jobs

Table 3 shows new green job generation for the Auckland region's economy industries with the greatest growth in green jobs.

Table 7. New 'green jobs' (MECs) for Auckland region's economy for selected industries

	2015	2020	2025	2030	2035	2040	2045	2050
Sheep, beef cattle and grain farming - methane inhibitor	0	0	0	0	1,362	1,388	1,419	1,469
Water, sewerage, drainage and waste services	74	526	1,005	1,305	1,583	1,868	2,175	2,431
Wholesale trade	27	194	370	481	583	688	801	896
Road transport - EV	4	30	327	1,403	3,710	7,873	14,360	19,674
Other transport, postal, courier, transport support and warehousing services. - domestic	33	236	450	585	711	839	977	1,094
Rental, hiring and real estate services	28	198	378	491	596	703	819	915
Professional, scientific, technical, administrative and support services	228	1,621	3,099	4,023	4,880	5,761	6,706	7,495
Local government administration	93	661	1,264	1,641	1,990	2,349	2,735	3,057
Central government administration, defence and public safety	44	310	592	768	932	1,100	1,280	1,431
Education and training	124	879	1,681	2,182	2,647	3,125	3,638	4,066

The sector with the largest growth is the EV road transport sector with 20,000 new jobs by 2050. The next largest are professional, scientific, technical, administrative and support services (7,500) and education and training (4,100). The growth patterns of Green Jobs reflect a mix of factors including the growth of new green industries, (e.g., Road transport – EV, and sheep, beef cattle and grain farming - methane inhibitor), industries which are defined as being a large proportion green (e.g., Local government administration, water, sewerage, drainage and waste services), and some that are defined as being a relatively small proportion green but that nonetheless grow enough to be significant (e.g., Wholesale trade, education and training). The growth in green jobs does not greatly alter the occupation profile of the economy given the already existing green jobs at the beginning of the scenario and green technologies tend not to be of the type that drastically change occupation structures[22].

[22] For example, a vehicle repair shop that switches to repairing EV instead of traditional internal combustion engine (ICE) vehicles may require fewer mechanics (electric motors have fewer parts than do ICEs), but such a business will likely require similar numbers of marketing, admin, sales, and other staff.

4 Conclusions

To comply with the Paris Agreement, the New Zealand government enacted the Zero Carbon Act in 2019 establishing emissions reduction targets by 2050 and the CCC as an independent adviser. In this advising role, the CCC published the "Ināia Tonu Nei: a low emissions future for Aotearoa" report where different pathways were assessed to reach a net zero goal by 2050. The CCC relied on a suite of techno-economic and macroeconomic models as part of the assessment. One of these models is the C-PLAN model, which is a CGE model that places the New Zealand economy in a global context.

Tātaki Auckland Unlimited requested M.E Research to assess the impacts of the pathways assessed by the CCC on the Auckland region's economy. M.E Research has developed a set of datasets, models and skills in the last few years that make this assessment possible. Hence, M.E Research extended an existing multi-regional CGE model to comply with the structure used by C-PLAN model using a different core dataset, namely a multi-regional SAM focusing on the Auckland region as the region of interest.

The model developed by M.E Research is a multi-regional, recursive dynamic CGE model that places the Auckland region's economy within the national context. One of the many advantages of using a multi-regional CGE model is the assessment of indirect impacts not only affecting producing sectors but consumption agents through commodity price signals, e.g., carbon price. The two scenarios assessed with the new CGE were:

1. a future baseline scenario driven by current climate policies, and
2. a future with decreasing GHG caps to reach the targets set in the Zero Carbon Act by 2050.

The emissions under the baseline scenario decrease over time due to expected technological advancements as well as regulatory constraints imposed on emissions-intensive sectors. The lower future baseline emissions combined with the availability of low-emissions technologies and the allocation of free permits to agricultural sectors result in relatively minimal impacts on regional GDP and welfare estimates from transitioning to a low-emissions economy under the policy scenario. Contrasted to the rest of New Zealand, the impacts on Auckland's regional economy are higher due to the difference in profile emissions (e.g., urban versus rural sectors), fewer low-emissions alternatives (e.g., methane-inhibitors are not critical), and indirect impacts from importing agricultural products with a higher price tag due to rising GHG prices.

With the help of key Auckland Council personnel, a subset of the assumptions originally formulated by the CCC were modified to appropriately represent Auckland's regional economy and transition pathways. Namely, the modifications included: 1) the expected growth trend of the iron and steel sector to realistically reflect the potential growth of the NZ Steel plant and 2) the reduction pathways for the Auckland region to assess the potential impacts from the targets published in "Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan". Although the overall results from this additional scenario did not change much when compared to the results under the CCC's original scenarios, the more drastic reduction targets for the Auckland region were reflected in higher carbon prices and reductions of regional GDP early in the time horizon.

These results show that while the GDP and welfare changes for the whole of New Zealand might be modest, they might be higher than expected for certain regions like Auckland due to the different emissions profiles generated by a different set of emissions-intensive sectors compared to the rest of New Zealand.

5 Definitions

Regions: refers to the Auckland region and the rest of New Zealand.

Removals: refers to the process of removing carbon dioxide from the atmosphere and locking it away in decades, centuries, or millennia.

Consumption: refers to the demand of commodities by government, households, and a representative investment account.

Household consumption: refers to the demand of commodities by an aggregated account representing households.

Exogenously: refers to the parameters that are external to the model, i.e., determined outside of the model.

Endogenously: refers to the variables that are internally generated or optimised by the model.

Absolute terms: refers to absolute change of the values of a specific indicator (e.g., GDP) when contrasting the baseline and policy scenarios.

Relative terms: refers to the percentage change of the values of a specific indicator (e.g., GDP) when contrasting the baseline and policy scenarios.

Consumer welfare: refers to the individual benefits derived from the consumption of goods and services.

6 References

Arrow, K.J., Debreu, G., 1954. Existence of an equilibrium for a competitive economy. Econometrica: Journal of the Econometric Society 265–290.

Auckland Council, 2020. Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan. Auckland, New Zealand.

Brooke, A., Kendrick, D., Meeraus, A., Rosenthal, R.E., 1998. GAMS, a User's Guide. Scientific Press, Washington DC.

Burniaux, J.-M., Truong, T., 2002. GTAP-E: An Energy-Environmental Version of the GTAP Model (GTAP Technical Paper No. 16). Global Trade Analysis Project (GTAP), Department of Agricultural Economics, Purdue University, West Lafayette, IN.

Capros, P., Van Regemorter, D., Paroussos, L., Karkatsoulis, P., Fragkiadakis, C., Tsani, S., Charalampidis, I., Revesz, T., Perry, M., Abrell, J., 2013. GEM-E3 model documentation. JRC Scientific and Policy Reports 26034.

Chen, Y.-H.H., 2017. The calibration and performance of a non-homothetic cde demand system for cge models. Journal of Global Economic Analysis 2, 166–214.

Climate Change Commission, 2021a. Ināia tonu nei: a low emissions future for Aotearoa. Wellington, New Zealand.

Climate Change Commission, 2021b. 2021 Draft Advice for Consultation. Wellington, New Zealand.

Concept Consulting, 2021. Modelling energy costs and prices - a technical note supporting Ināia tonu nei.

Dixon, P.B. & Jorgenson, D.W. 2013a. Handbook of Computable General Equilibrium Modelling, Volume 1A. Elsevier, Amsterdam.

Dixon, P.B. & Jorgenson, D.W. 2013b. Handbook of Computable General Equilibrium Modelling, Volume 1B. Elsevier, Amsterdam.

Hancock, A (2010). How green is my occupation classification? Statistics New Zealand

Hosoe, N., Gasawa, K., Hashimoto, H. 2010. Textbook of computable general equilibrium modelling: programming and simulations. Palgrave MacMillan, London. https://doi.org/10.1057/9780230281653

Jacoby, H.D., Wing, I.S., 1999. Adjustment time, capital malleability and policy cost. The Energy Journal 20.

Johansen, L., 1964. A Multi-Sectoral Study of Economic Growth. North-Holland Publishing Company.

Klepper, G., Peterson, S., Springer, K., 2003. DART97: A description of the multi-regional, multi-sectoral trade model for the analysis of climate policies. Kiel Working Paper.

Leontief, W.W., 1936. Quantitative input and output relations in the economic systems of the United States. The review of economic statistics 105–125.

Matsuyama, K., Ushchev, P., 2017. Beyond CES: three alternative classes of flexible homothetic demand systems. Global Poverty Research Lab Working Paper.

McDonald, G., Kingi, T., Kim, J.-H., Dowling, L., Journeaux, P., Dunningham, A., Wakelin, S., Monge, J., Hock, B., 2021. Assessing the economic implications of land returned to the Te Hiku iwi collective, Tai Tokerau, Aotearoa New Zealand. Journal of Rural Studies 84, 108–123.

Ministry for the Environment, 2022. Overview of industrial allocation [WWW Document]. URL https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/ets/participating-in-the-nz-ets/overview-industrial-allocation/

Ministry for the Environment, 2019a. New Zealand's Greenhouse Gas Inventory 1990–2017 (No. 1411), Submitted to the United Nations Framework Convention on Climate Change. Wellington, New Zealand.

Ministry for the Environment, 2019b. New Zealand's Fourth Biennial Report under the United Nations Framework Convention on Climate Change. Wellington, New Zealand.

Ministry of Transport, 2017. Transport Outlook: Future State. Wellington, New Zealand.

Murray, C (2008). Green Jobs: Potential in the Auckland Region. Auckland Regional Council.

Paltsev, S., Reilly, J.M., Jacoby, H.D., Eckaus, R.S., McFarland, J.R., Sarofim, M.C., Asadoorian, M.O., Babiker, M.H., 2005. The MIT emissions prediction and policy analysis (EPPA) model: version 4 (No. 125). MIT joint program on the science and policy of global change, Cambridge, Massachusetts.

Parliament of New Zealand, 2019. Climate Change Response (Zero Carbon) Amendment Act 2019.

Rutherford, T. F., 1999. Recursive versus Intertemporal: A Worked Example [WWW Document]. URL https://www.gamsworld.org/mpsge/debreu/dynamics/note.htm

Rutherford, T. F., 2004. Tools for Building National Economic Models Using State-Level IMPLAN Social Accounts [WWW Document]. URL https://www.gamsworld.org/mpsge/debreu/implan98.htm

Rutherford, T. F., 1999. Applied general equilibrium modeling with MPSGE as a GAMS subsystem: An overview of the modeling framework and syntax. Computational economics 14, 1–46.

Smith, N.J., Zhang, Y., Cardwell, R.J., McDonald, G.W., Kim, J.-H., Murray, C.A., 2015. Development of a Regional Social Accounting Framework for New Zealand (GNS Science Technical Report). GNS Science, Lower Hutt, New Zealand.

Statistics New Zealand, 2021a. Greenhouse gas emissions by region (industry and household): Year ended 2019 [WWW Document]. URL https://www.stats.govt.nz/information-releases/greenhouse-gas-emissions-by-region-industry-and-household-year-ended-2019

Statistics New Zealand, 2021b. Subnational population projections: 2018(base)–2048 [WWW Document]. URL https://www.stats.govt.nz/information-releases/subnational-population-projections-2018base2048

Statistics New Zealand, 2021c. Regional gross domestic product: Year ended March 2021 [WWW Document]. URL https://www.stats.govt.nz/information-releases/regional-gross-domestic-product-year-ended-march-2021

Strutt, A., 2021. GTAP to NZ sectors. Personal Communication.

Transpower New Zealand, 2018. Auckland Strategy Direction.

Tuatagaloa, Penelope (2014). Green jobs in Auckland – an update. Auckland Council working report, WR2014/002

Walras, L., 1874. Elements d'économie pure, ou théorie de la richesse sociale.

Winchester, N., White, D., 2022. The Climate PoLicy ANalysis (C-PLAN) Model, Version 1.0. Energy Economics 108, 105896. https://doi.org/10.1016/j.eneco.2022.105896

7 Appendix 1 – Industry Concordance

IO106 code	IO106_name	c-plan code	c-plan name
1	Horticulture and fruit growing	hor	Horticulture
1	Horticulture and fruit growing	bh_hor	bioheat for horticulture
1	Horticulture and fruit growing	eh_hor	electric heat for horticulture
2	Sheep, beef cattle and grain farming	bas	Beef And Sheep Farming
2	Sheep, beef cattle and grain farming	bas1	methane inhibitor - sheep & beef
3	Dairy cattle farming	rmk	Dairy Farming
3	Dairy cattle farming	rmk1	methane inhibitor - dairy
4	Poultry, deer and other livestock farming	oap	Other Animal Products
5	Forestry and logging	frs	Forestry
6	Fishing and aquaculture	fsh	Fishing
7	Agriculture, forestry and fishing support services	ser	Other Services
8	Coal mining	col	Coal Mining
9	Oil and gas extraction	cru	Crude Oil Extraction
9	Oil and gas extraction	gas	Gas Extraction And Distribution
10	Metal ore and non-metallic mineral mining and quarrying	oxt	Other Mining
11	Exploration and other mining support services	oxt	Other Mining
12	Meat and meat product manufacturing	mtp	Meat Products
12	Meat and meat product manufacturing	bh_mtp	bioheat for meat products
12	Meat and meat product manufacturing	eh_mtp	electric heat for meat products
13	Seafood processing	mtp	Meat Products
13	Seafood processing	bh_mtp	bioheat for meat products
13	Seafood processing	eh_mtp	electric heat for meat products
14	Dairy product manufacturing	mil	Dairy Processing
14	Dairy product manufacturing	bh_mil	bioheat for dairy products
14	Dairy product manufacturing	eh_mil	electric heat for dairy products
15	Fruit, oil, cereal and other food product manufacturing	ofd	Other Food Products
15	Fruit, oil, cereal and other food product manufacturing	bh_ofd	bioheat for other food products
15	Fruit, oil, cereal and other food product manufacturing	eh_ofd	electric heat for other food products
16	Beverage and tobacco product manufacturing	ofd	Other Food Products
16	Beverage and tobacco product manufacturing	bh_ofd	bioheat for other food products
16	Beverage and tobacco product manufacturing	eh_ofd	electric heat for other food products
17	Textile and leather manufacturing	omf	Other Manufacturing
17	Textile and leather manufacturing	bh_omf	bioheat for other manufacturing
17	Textile and leather manufacturing	eh_omf	electric heat for other manufacturing
18	Clothing, knitted products and footwear manufacturing	omf	Other Manufacturing
18	Clothing, knitted products and footwear manufacturing	bh_omf	bioheat for other manufacturing

IO106 code	IO106_name	c-plan code	c-plan name
18	Clothing, knitted products and footwear manufacturing	eh_omf	electric heat for other manufacturing
19	Wood product manufacturing	wpp	Wood And Paper Products
19	Wood product manufacturing	bh_wpp	bioheat for wood, pulp and paper products
19	Wood product manufacturing	eh_wpp	electric heat for wood, pulp and paper products
20	Pulp, paper and converted paper product manufacturing	wpp	Wood And Paper Products
20	Pulp, paper and converted paper product manufacturing	bh_wpp	bioheat for wood, pulp and paper products
20	Pulp, paper and converted paper product manufacturing	eh_wpp	electric heat for wood, pulp and paper products
21	Printing	wpp	Wood And Paper Products
21	Printing	bh_wpp	bioheat for wood, pulp and paper products
21	Printing	eh_wpp	electric heat for wood, pulp and paper products
22	Petroleum and coal product manufacturing	oil	Refined Oil Products
23	Basic chemical and basic polymer manufacturing	crp	Chemical, Rubber And Plastic Products
24	Fertiliser and pesticide manufacturing	crp	Chemical, Rubber And Plastic Products
25	Pharmaceutical, cleaning and other chemical manufacturing	crp	Chemical, Rubber And Plastic Products
26	Polymer product and rubber product manufacturing	crp	Chemical, Rubber And Plastic Products
27	Non-metallic mineral product manufacturing	nmm	Non-Metallic Minerals (e.g. Cement)
28	Primary metal and metal product manufacturing	nfm	Iron, Steel And Non-Ferrous Metals (e.g. Aluminum)
29	Fabricated metal product manufacturing	fmp	Fabricated Metal Products
30	Transport equipment manufacturing	mvh	Motor Vehicle And Parts
31	Electronic and electrical equipment manufacturing	omf	Other Manufacturing
31	Electronic and electrical equipment manufacturing	bh_omf	bioheat for other manufacturing
31	Electronic and electrical equipment manufacturing	eh_omf	electric heat for other manufacturing
32	Machinery manufacturing	omf	Other Manufacturing
32	Machinery manufacturing	bh_omf	bioheat for other manufacturing
32	Machinery manufacturing	eh_omf	electric heat for other manufacturing
33	Furniture manufacturing	omf	Other Manufacturing
33	Furniture manufacturing	bh_omf	bioheat for other manufacturing
33	Furniture manufacturing	eh_omf	electric heat for other manufacturing
34	Other manufacturing	omf	Other Manufacturing
34	Other manufacturing	bh_omf	bioheat for other manufacturing

IO106 code	IO106_name	c-plan code	c-plan name
34	Other manufacturing	eh_omf	electric heat for other manufacturing
35	Electricity generation and on-selling	eco	Electricity Generation - coal
35	Electricity generation and on-selling	ega	Electricity Generation - gas
35	Electricity generation and on-selling	ehy	Electricity Generation - hydro
35	Electricity generation and on-selling	ews	Electricity Generation - wind/solar
35	Electricity generation and on-selling	eot	Electricity Generation - geothermal
35	Electricity generation and on-selling	eot_ccs	Electricity Generation - geothermal with CCS
36	Electricity transmission and distribution	tnd	Electricity Generation - transmission and distribution
37	Gas supply	ser	Other Services
38	Water supply	ser	Other Services
39	Sewerage and drainage services	ser	Other Services
40	Waste collection, treatment and disposal services	ser	Other Services
41	Residential building construction	cns	Construction
42	Non-residential building construction	cns	Construction
43	Heavy and civil engineering construction	cns	Construction
44	Construction services	cns	Construction
45	Basic material wholesaling	ser	Other Services
46	Machinery and equipment wholesaling	ser	Other Services
47	Motor vehicle and motor vehicle parts wholesaling	ser	Other Services
48	Grocery, liquor and tobacco product wholesaling	ser	Other Services
49	Other goods and commission based wholesaling	ser	Other Services
50	Motor vehicle and parts retailing	ser	Other Services
51	Fuel retailing	ser	Other Services
52	Supermarket and grocery stores	ser	Other Services
53	Specialised food retailing	ser	Other Services
54	Furniture, electrical and hardware retailing	ser	Other Services
55	Recreational, clothing, footwear and personal accessory retailing	ser	Other Services
56	Department stores	ser	Other Services
57	Other store based retailing; non-store and commission based retailing	ser	Other Services
58	Accommodation	afs	Accommodation And Food Services
59	Food and beverage services	afs	Accommodation And Food Services
60	Road transport	rtp	Road Transport
60	Road transport	rtp1	EV - road transport
61	Rail transport	ser	Other Services
62	Other transport	wtp	Water Transport - Domestic
62	Other transport	wtpi	Water Transport - International
63	Air and space transport	atp	Air Transport - Domestic
63	Air and space transport	atpi	Air Transport - International

IO106 code	IO106_name	c-plan code	c-plan name
64	Postal and courier pick up and delivery services	ser	Other Services
65	Transport support services	ser	Other Services
66	Warehousing and storage services	ser	Other Services
67	Publishing (except internet and music publishing)	ser	Other Services
68	Motion picture and sound recording activities	ser	Other Services
69	Broadcasting and internet publishing	ser	Other Services
70	Telecommunications services including internet service providers	ser	Other Services
71	Library and other information services	ser	Other Services
72	Banking and financing; financial asset investing	ser	Other Services
73	Life insurance	ser	Other Services
74	Health and general insurance	ser	Other Services
75	Superannuation funds	ser	Other Services
76	Auxiliary finance and insurance services	ser	Other Services
77	Rental and hiring services (except real estate); non-financial asset leasing	ser	Other Services
78	Residential property operation	ser	Other Services
79	Non-residential property operation	ser	Other Services
80	Real estate services	ser	Other Services
81	Owner-occupied property operation	ser	Other Services
82	Scientific, architectural and engineering services	ser	Other Services
83	Legal and accounting services	ser	Other Services
84	Advertising, market research and management services	ser	Other Services
85	Veterinary and other professional services	ser	Other Services
86	Computer system design and related services	ser	Other Services
87	Travel agency and tour arrangement services	ser	Other Services
88	Employment and other administrative services	ser	Other Services
89	Building cleaning, pest control and other support services	ser	Other Services
90	Local government administration	ser	Other Services
91	Central government administration and justice	ser	Other Services
92	Defence	ser	Other Services
93	Public order, safety and regulatory services	ser	Other Services
94	Preschool education	ser	Other Services
95	School education	ser	Other Services
96	Tertiary education	ser	Other Services

IO106 code	IO106_name	c-plan code	c-plan name
97	Adult, community and other education	ser	Other Services
98	Hospitals	ser	Other Services
99	Medical and other health care services	ser	Other Services
100	Residential care services and social assistance	ser	Other Services
101	Heritage and artistic activities	ser	Other Services
102	Sport and recreation activities	ser	Other Services
103	Gambling activities	ser	Other Services
104	Repair and maintenance	ser	Other Services
105	Personal services; domestic household staff	ser	Other Services
106	Religious services; civil, professional and other interest groups	ser	Other Services

8 Appendix 2 – Baseline projections

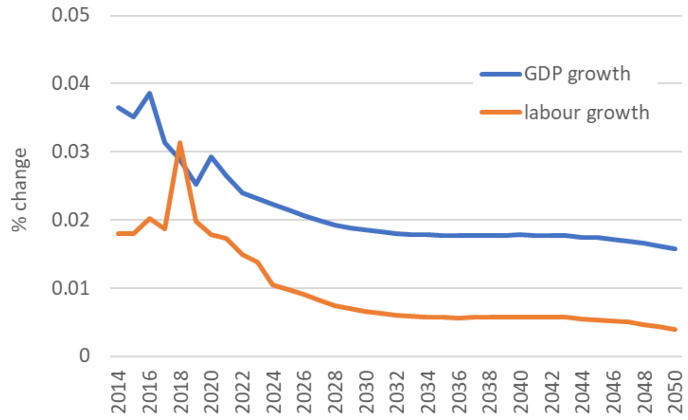

Figure 21. GDP and labour growth projections from C-PLAN study

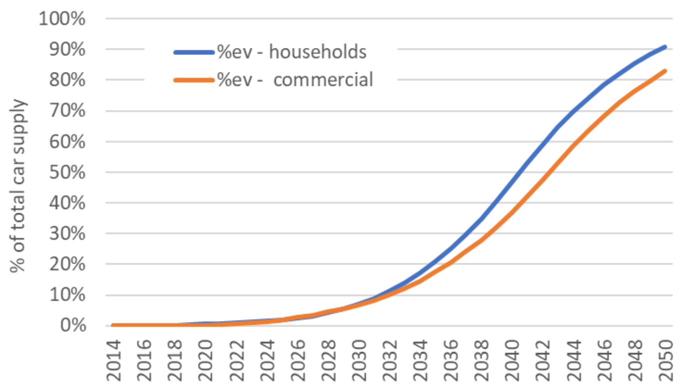

Figure 22. EV integration as a % of total car supply from C-PLAN study

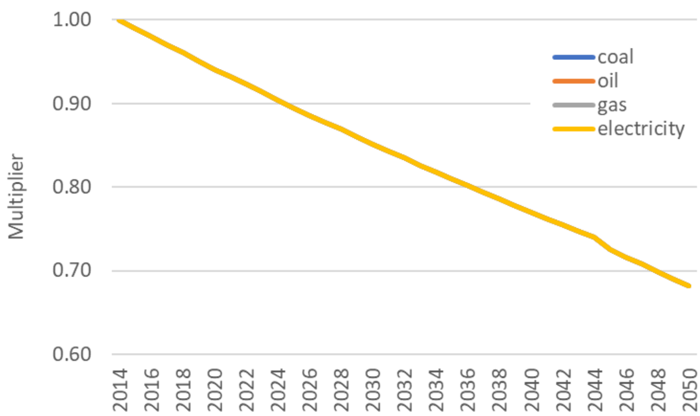

Figure 23. Projections of autonomous energy efficiency improvements from C-PLAN study

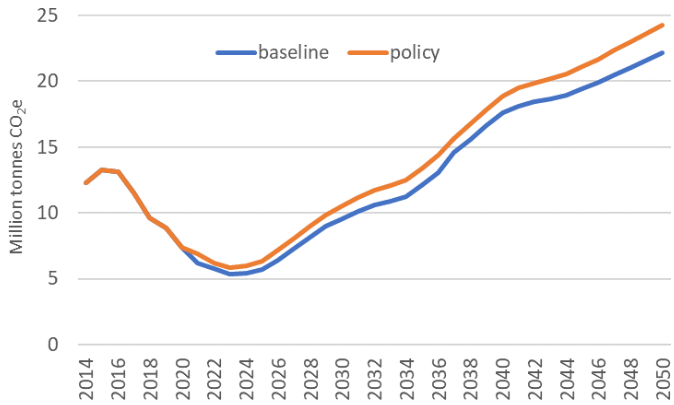

Figure 24. National afforestation projections obtained from MPI

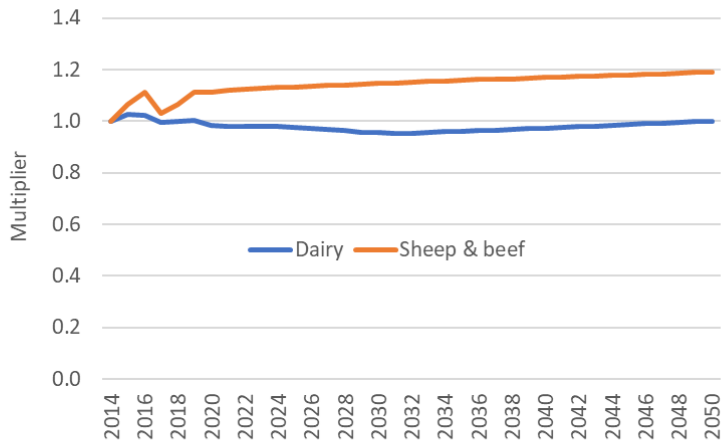

Figure 25. Land productivity multiplier from C-PLAN study

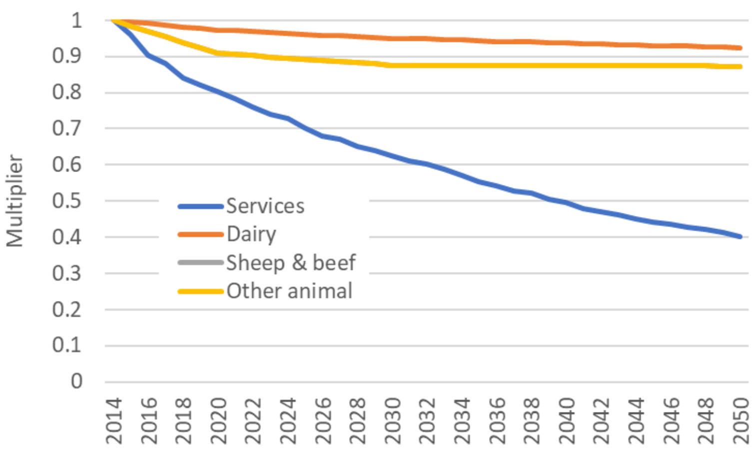

Figure 26. Autonomous GHG emission reduction matching projections from New Zealand's 4th Biennial Report under the UNCCC

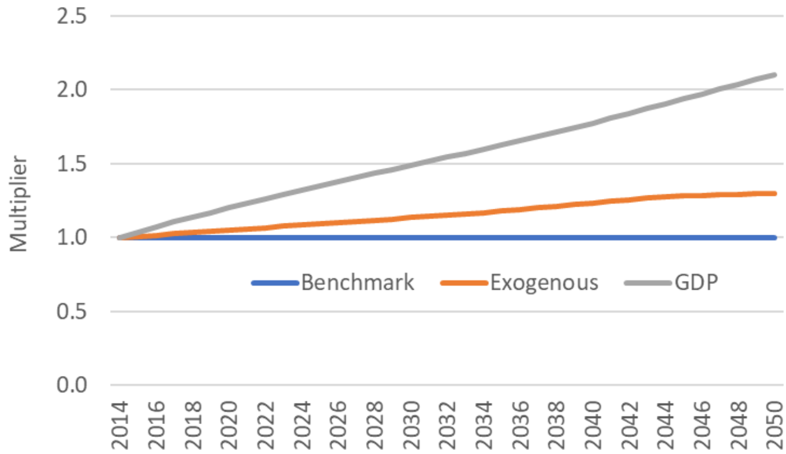

Figure 27. Sectoral output constraints from C-PLAN study

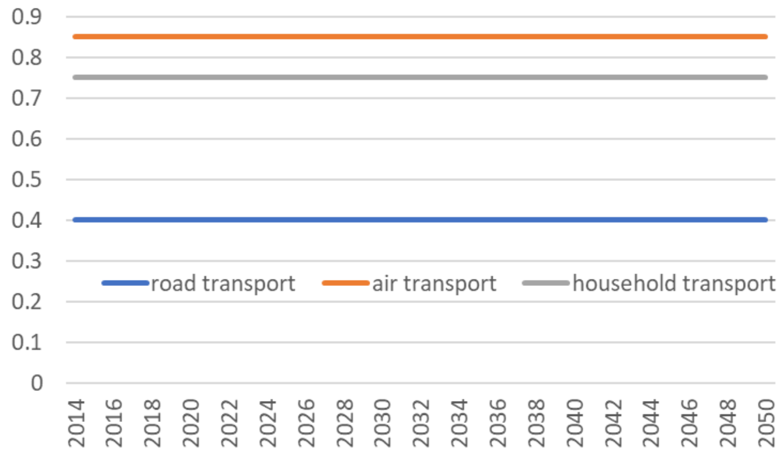

Figure 28. Stone-Geary shift parameters to target consumption for certain commodities from C-PLAN study

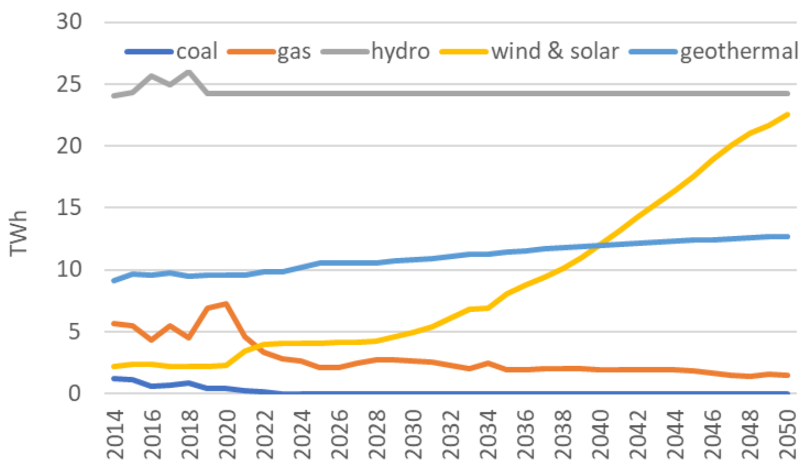

Figure 29. Projections of national electricity generation produced by the ENZ model

9 Appendix 3 – Green Jobs Definition

Each industry used for the employment impact analysis is considered to comprise a certain proportion of 'green jobs' according to the following table.

	Industry Description	Green Jobs Share
1	Horticulture and fruit growing - normal	0.39
2	Horticulture and fruit growing - bioheat	1.00
3	Horticulture and fruit growing - electric heat	1.00
4	Sheep, beef cattle and grain farming - normal	0.22
5	Sheep, beef cattle and grain farming - methane inhibitor	1.00
6	Dairy cattle farming - normal	0.00
7	Dairy cattle farming - methane inhibitor	1.00
8	Poultry, deer and other livestock farming	0.09
9	Forestry and logging	0.35
10	Fishing and aquaculture	0.05
11	Agriculture, forestry and fishing support services	0.16
12	Mining, quarrying, exploration and other mining support services	0.00
13	Oil and gas extraction - crude oil	0.00
14	Oil and gas extraction - gas	0.00
15	Meat and meat product manufacturing - normal	0.01
16	Meat and meat product manufacturing - bioheat	1.00
17	Meat and meat product manufacturing - electric heat	1.00
18	Other food manufacturing - normal	0.01
19	Other food manufacturing - bioheat	1.00
20	Other food manufacturing - electric heat	1.00
21	Dairy product manufacturing - normal	0.01
22	Dairy product manufacturing - bioheat	1.00
23	Dairy product manufacturing - electric heat	1.00
24	Beverage and tobacco product manufacturing - normal	0.01
25	Beverage and tobacco product manufacturing - bioheat	1.00
26	Beverage and tobacco product manufacturing - electric heat	1.00
27	Textile, leather, clothing and footwear manufacturing - normal	0.01
28	Textile, leather, clothing and footwear manufacturing - bioheat	1.00
29	Textile, leather, clothing and footwear manufacturing - electric heat	1.00
30	Wood product manufacturing - normal	0.10
31	Wood product manufacturing - bioheat	1.00
32	Wood product manufacturing - electric heat	1.00
33	Pulp, paper and converted paper product manufacturing - normal	0.01
34	Pulp, paper and converted paper product manufacturing - bioheat	1.00
35	Pulp, paper and converted paper product manufacturing - electric heat	1.00
36	Printing - normal	0.01
37	Printing - bioheat	1.00
38	Printing - electric heat	1.00
39	Petroleum and coal product manufacturing	0.01
40	Chemical, polymer and rubber product manufacturing	0.05

	Industry Description	Green Jobs Share
41	Non-metallic mineral product manufacturing	0.01
42	Primary metal and metal product manufacturing	0.01
43	Fabricated metal product manufacturing	0.05
44	Transport equipment manufacturing	0.05
45	Machinery and equipment manufacturing - normal	0.05
46	Machinery and equipment manufacturing - bioheat	1.00
47	Machinery and equipment manufacturing - electric heat	1.00
48	Furniture and other manufacturing - normal	0.01
49	Furniture and other manufacturing - bioheat	1.00
50	Furniture and other manufacturing - electric heat	1.00
51	Electricity generation and supply - coal	0.00
52	Electricity generation and supply - gas	0.00
53	Electricity generation and supply - hydro	1.00
54	Electricity generation and supply - wind/solar	1.00
55	Electricity generation and supply - geothermal	1.00
56	Electricity generation and supply - geothermal CCS	1.00
57	Electricity generation and supply - transmission and distribution	0.70
58	Gas supply	0.40
59	Water, sewerage, drainage and waste services	0.84
60	Construction	0.09
61	Wholesale trade	0.01
62	Retail Trade	0.01
63	Accommodation and food services	0.01
64	Road transport - normal	0.23
65	Road transport - EV	1.00
66	Other transport, postal, courier, transport support and warehousing services. - domestic	0.06
67	Other transport, postal, courier, transport support and warehousing services. - international	0.06
68	Air and space transport - domestic	0.01
69	Air and space transport - international	0.01
70	Information media and telecommunications	0.02
71	Finance	0.01
72	Insurance and superannuation funds	0.01
73	Auxiliary finance and insurance services	0.01
74	Rental, hiring and real estate services	0.05
75	Ownership of owner-occupied dwellings	0.00
76	Professional, scientific, technical, administrative and support services	0.05
77	Local government administration	0.40
78	Central government administration, defence and public safety	0.05
79	Education and training	0.06
80	Health care and social assistance	0.01
81	Arts and recreation services	0.03
82	Personal and other services	0.02