Economic impact analysis of 2050 emissions targets

A dynamic Computable General Equilibrium analysis

NZIER final report to Ministry for the Environment

18 June 2018

About NZIER

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Each year NZIER devotes resources to undertake and make freely available economic research and thinking aimed at promoting a better understanding of New Zealand's important economic challenges.

NZIER was established in 1958.

Authorship

This paper was prepared at NZIER by John Ballingall and Dr Daniel Pambudi. Dr Erwin Corong (NZIER Associate) and Dr Adolf Stroombergen (Infometrics) provided valuable technical assistance and peer review.

It was quality approved by Peter Clough.

The assistance of officials in numerous government agencies is gratefully acknowledged.

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Executive summary

Research objectives and methodology

NZIER has been asked to explore the economic impacts of New Zealand adopting different greenhouse gas emissions targets in 2050.

We use a detailed model of the entire economy and its emissions

We use a dynamic Computable General Equilibrium (CGE) model of the New Zealand economy, split into 111 industries, to investigate a range of potential scenarios and 2050 targets. CGE models have been widely used in New Zealand and overseas for climate change analysis.

Our model allows us to explore the inevitable trade-offs involved with adjusting to a lower-emissions future.

We examine how the economy changes in response to the imposition of various emissions targets – and hence carbon prices – under a range of scenarios that consider innovation in energy, transport and agriculture, along with increased rates of net sequestration from forestry.

CGE scenario modelling is helpful for answering "What if…?" questions…

The scenarios (outlined overleaf in Table 1) were developed with officials, drawing on Vivid, Motu and Concept (2018). We do not assess the likelihood of the various assumptions underpinning these innovation scenarios occurring. They are not NZIER's view on what *will* happen.

For example, our model cannot predict if or when a methane vaccine might be introduced to New Zealand, but it *can* estimate how the economy and its emissions profile would likely adjust in response to such a vaccine's introduction.

Our modelling allows us to consider the question:

> *If various innovations occur, what will be the economic impacts of a net zero 2050 emissions target?*

...based on a set of assumptions about New Zealand's economy and emissions profile out to 2050

Projecting how the New Zealand economy will develop over the next 35 years is inherently complex. We cannot predict with any certainty future global financial crises or new industries that may emerge in response to technological changes such as artificial intelligence.

When we also introduce industry-level greenhouse gas emissions projections into the picture, the modelling task becomes even more challenging. Predicting the global response to the threat of climate change is difficult. This means there is considerable uncertainty about international carbon prices and how much investment will occur in emissions-reducing technology.

Further, we do not know how global consumer preferences will change regarding high- or low-emissions products.

To the extent that we do not predict breakthrough technologies that significantly reduce emissions at very low cost, our results will over-estimate the costs of transitioning to a lower-emissions economy.

Further, we do not consider the physical impacts of climate change on crop yields, coastal erosion, human and animal health, or infrastructure damage from storms.

This provides part of the evidence base to inform policy discussions

Under these circumstances, we need to make many assumptions about how to model the economic and emissions outlook to 2050. Many of these assumptions will be shown to be incorrect over time. However, this is true of all economic and climate change models.

The role of an economic model such as ours is to compare and contrast different scenarios in order to provide empirical insights about costs and benefits under a consistent theoretical framework. Or as Nixon and Yeabsley (2005) put it:

> *In economics, we attempt to illustrate through the modelling process a system of relationships which, although abstract, tries to capture the economically salient elements of the real world….*
>
> *The potential cost of this approach, of course, is that the process of abstraction has eliminated characteristics that are vital to the full understanding of the question under discussion.*

With this in mind, we hope our analysis contributes to a discussion in New Zealand about the nature and magnitude of the economic trade-offs we are prepared to accept to meet different 2050 emissions targets.

We have sought to be as transparent as possible about our methodology, data and assumptions. A full list of caveats is presented in chapter 1.2.

Additional scenarios and sensitivity analysis around key assumptions and parameters can be considered in future research.

We explore 2050 targets of 50%, 75% and 100% of 1990 emissions

The scenarios described below are assessed against a range of potential emissions targets, which reflect different levels of ambition:

- 100% reduction on 1990 gross levels by 2050, or 'zero net emissions'
- 75% reduction on 1990 gross levels by 2050
- Existing target of 50% reduction on 1990 gross levels by 2050.

These targets use the 'gross-net' methodology. We determine the 50/75/ZNE reduction in emissions by 2050 from a 1990 starting point of 64.6Mt CO2-e.

We then subtract assumed forestry sequestration to give us the maximum permissible gross emissions in 2050 after having accounted for the effects of forestry in meeting each target. We refer to the 100% target as 'zero net emissions' or ZNE in this report.

We do not attempt to estimate the costs of the various innovations that we model, or determine who would bear them and when. We simply assume they occur, and examine their implications. As such, this CGE modelling should not be seen as a cost-benefit analysis.

Our scenarios incorporate a considerable amount of technological change and afforestation

Table 1 Overview of scenarios

Scenario name	Key features
Baseline	Current policy settings and energy efficiency trends; biological emissions excluded; $20 carbon price; strong rest of world action on climate change; phase out of free allocation; EV uptake of 65% of light vehicle fleet by 2050; no access to international permits.
Core scenarios	
Ag innovation	Biological emissions included; methane vaccine introduced in 2030, reducing biological emissions by 30%; lower global demand for dairy and meat exports; expansion of horticulture; large expansion in net sequestration.
Energy innovation	Biological emissions included; widespread, more rapid energy efficiency improvements; EV uptake to 95% of light vehicle fleet and 50% of heavy vehicle fleet; 98% renewable electricity from 2035. No additional net sequestration above the baseline.
Wide innovation	All measures in Ag and Energy innovation scenarios combined.
Sensitivity analysis	
Wide innovation + trade	Wide innovation plus access to international permits which increase in price from $20 now to $50 by 2030 and either $100 or $150 by 2050.
Wide innovation + weak RoW	Wide innovation but global response to climate change is weak; New Zealand exporters face competitiveness challenges; free allocation held steady.
Wide innovation, alternative forestry	Wide innovation for 50% and 75% targets that incorporates higher net sequestration (40Mt) than in core scenarios; wide innovation for ZNE target with lower net sequestration (40Mt) than in core scenario.

Source: NZIER

Note that there is no additional net sequestration to the baseline assumed in the Energy innovation scenarios. This is so that the economic impacts of changes in the energy and transport industries can be identified separately in this scenario from changes to afforestation.

Projecting the likely response of innovation and afforestation to higher carbon prices is challenging

Our model does not incorporate 'endogenous technological change'. That means innovation does not respond to the higher carbon prices associated with imposing an emissions target *within the model itself*.

The same applies for the response of forestry owners to higher carbon prices. Our model cannot predict the extent of new planting or avoided harvesting as carbon process rise.

We have to make choices about innovation and afforestation outside of the model, and build them into our scenario design.

In reality, all discussions about innovation will be conditional on the expected carbon price. If you look at the innovation assumptions in Table 1 relative to current, low carbon prices, they look optimistic.

But if – as our modelling indicates – carbon prices will rise substantially to incentivise firms to move towards lower-emissions production techniques that are consistent with ambitious emissions targets, then some assumptions we have used might be considered conservative.

We recognise these limitations to our analysis, but ultimately we have to assume something, even if we know it's unlikely to be a perfect approximation of economic agents' behaviour.

We explore the economic impacts against a status quo that represents the current government emissions target of 50% by 2050

It is customary in CGE modelling to compare scenario results against a baseline in which nothing else changes.

However, it can be argued that the likelihood of the New Zealand economic and emissions profiles developing as per the baseline assumptions is not high. The government's existing stated emissions target for 2050 is for a 50% reduction, and we would expect policy changes to push us towards that target over time.

Therefore, an alternative way of thinking about economic impacts is to compare the results for the 75% and ZNE targets against those from the 50% 'status quo' target, rather than the 'do-nothing' baseline.

This aligns more closely to the approach that is required for regulatory impact analysis in New Zealand, where the focus is on the marginal change of policy options from the status quo, rather than from a do-nothing baseline.

Based on guidance from officials, we refer to the Wide innovation, 50% target as the status quo in this report.

As Table 1 summarises, this status quo incorporates a considerable amount of innovation and afforestation, including EV uptake by 2050 of 95% of the light vehicle fleet and 50% of the heavy vehicle fleet, a methane vaccine phased in between 2030 and 2035, a shift to 98% renewable electricity from 2035, and afforestation of 25Mt by 2050.

However, given the relatively high carbon prices that our modelling delivers when we impose ambitious emissions targets, such changes from the situation today are probably not unreasonable.

Key findings

We estimate that moving from the current situation to the status quo scenario will cost $28 billion by 2050

Taking this comparison against status quo approach assumes that the economy will look more like the Wide innovation, 50% target scenario than the baseline, and does not explicitly recognise the costs of getting to the 50% target.

However, our modelling suggests that there will be significant costs involved in getting to the Wide innovation, 50% target status quo.

We estimate real GDP in the status quo to be $28.0 billion lower than baseline by 2050. On an annual average basis, this equates to $8.6 billion per year.

Employment will be 1.2% and real wages 6.1% below baseline by 2050.

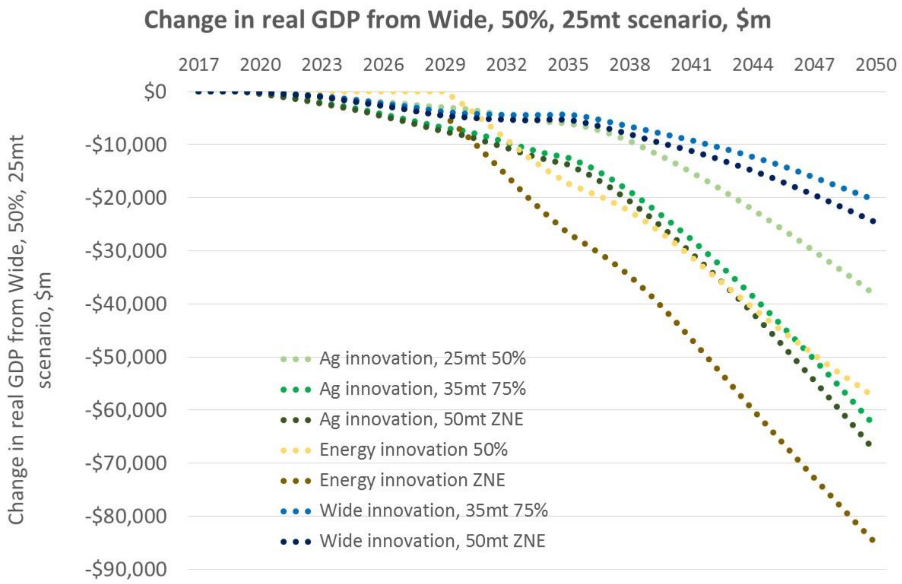
The marginal impacts reported on below need to be seen as additional to these costs.

Achieving ambitious emissions targets will see real GDP fall by between an additional $20-80 billion by 2050, compared to the status quo

The real GDP impacts are shown in Figure 1. The impacts, relative to the 2050 status quo, range from $20.5 billion (4.0%) for the Wide innovation, 75% target scenario to $85.2 billion (16.8%) for the Energy innovation, ZNE scenario.

Figure 1 Economic impacts of emissions targets compared to status quo

Change in $ millions from Wide innovation, 50% target scenario



Source: NZIER

The GDP impacts are moderate in the early part of the projection period.

The kinked time profile of the GDP impacts in the Ag innovation and Wide innovation scenarios demonstrate the economic gains from introducing a methane vaccine gradually between 2030 and 2035. The vaccine improves the productivity of the dairy and sheep and beef sectors, which temporarily mitigates some of the negative impacts of the higher emissions targets.

This is partly offset by the shift in global demand preferences away from emissions-intensive food such as meat and dairy products, and the GDP impacts resume their downward trend once the vaccine is fully implemented by 2035.

The small differences between the 75% and ZNE scenarios in the Ag and Wide innovation scenarios, relative to the differences between 50% and 75%, are due largely to the forestry assumptions employed. Between 50% and 75%, net sequestration increases by 10Mt; between 75% and ZNE it increases by 15Mt, which reduces the abatement burden on the rest of the economy.

Note that, by design, the Energy innovation scenarios do not incorporate any significant change in net sequestration, hence their economic costs are considerably higher. However, given the high carbon prices this scenario generates, we would expect the forestry sector to respond by planting more trees. This would reduce the economic costs in the Energy scenarios

In all core scenarios, the economy continues to grow

In the baseline, average economic growth between 2017 and 2050 is 2.2%. In all scenarios, the average growth rate remains at 1.5% or higher (Table 2).

Across the core scenarios, the difference between the ZNE target average growth rates and the 50% target growth rates is around -0.2%.

Table 2 Average economic growth across scenarios

Compound Average Growth Rate in real GDP, 2017-2050

	Baseline	Ag	Ag	Ag	Energy	Energy	Wide	Wide	Wide
Target	**-**	**50%**	**75%**	**ZNE**	**50%**	**ZNE**	**50%**	**75%**	**ZNE**
Average GDP per year, $bn	$386	$367	$359	$357	$359	$349	$377	$371	$370
Average GDP growth rate	2.2%	1.8%	1.6%	1.6%	1.7%	1.5%	2.1%	1.9%	1.9%
Difference in av. growth rate from status quo	+0.17%	-0.24%	-0.41%	-0.44%	-0.37%	-0.57%	-	-0.13%	-0.15%
Difference in av. growth rate from baseline	-	-0.41%	-0.58%	-0.61%	-0.54%	-0.73%	-0.17%	-0.29%	-0.32%

Source: NZIER

Households will be better off than they are now, but worse off than they would have been in the status quo scenario

We measure the impacts on households through changes in real Gross National Disposable Income (RGDNI) per household.

RGDNI is a measure of household welfare as it adjusts changes in GDP (or income) for movements in export and import prices that affect households' purchasing power. It is not the same as household income.

Per-household welfare is projected to be $275,000 in the status quo by 2050. As Figure 2 shows, it will be between $13,600 (4.9%) and $46,800 (13.6%) lower by 2050 for the ZNE scenarios.

Note, however, that the 2050 level of per-household RGNDI will be higher than the current level of around $183,000.

On an annual average basis, the per-household RGDNI impacts are shown in Table 3. For the ZNE scenarios, the per-household annual average RGNDI costs are between $4,600 and $16,300, compared to the status quo.

Table 3 Welfare impacts per household

Per household RGDNI, annual average, 2017-2050

Scenario	Baseline	Ag	Ag	Ag	Energy	Energy	Wide	Wide	Wide
Target	**-**	**50%**	**75%**	**ZNE**	**50%**	**ZNE**	**50%**	**75%**	**ZNE**
Average annual per-household RGDNI, $000s	232	220	216	215	216	210	226	223	222
Difference from status quo, $000s	+5.2	-6.0	-10.8	-11.7	-10.5	-16.3	-	-3.8	-4.6

Source: NZIER

These welfare decreases are due to higher costs of goods and services that are pushed up by higher carbon prices, and a softer labour market outlook.

Employment is expected to fall by between 0.9% and 2.7% below the status quo by 2050 in the ZNE scenarios (Figure 3). The lower the target, the lower the employment impact.

Note that we incorporate expected labour force growth into our baseline scenario, so these reported employment declines are from a higher level than current employment:

- In our baseline, employment grows by 22.2% between 2017 and 2050.
- In the status quo, employment grows by 20.7% from 2017.
- In the Wide innovation, ZNE scenario, this growth from 2017 drops marginally to 19.6%.

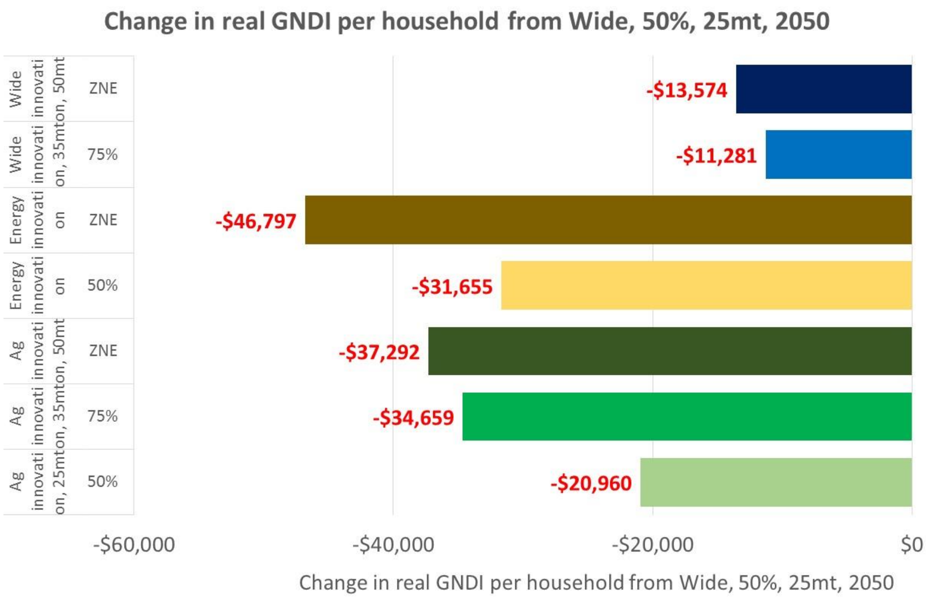
We assume labour is able to move freely between industries as they expand or contract in response to the introduction of emissions targets. Our modelling framework also pushes employment back towards its baseline over time, with the lingering effects of weaker labour demand being felt through real wage declines.

The large drop in employment in the Energy innovation scenarios from 2030 occurs because we are comparing against the Wide innovation, 50% status quo scenario, in which employment improves when a methane vaccine is introduced in 2030.

Real wages also fall substantially across these core scenarios – by a minimum of 6.7% below status quo by 2050 for the Wide innovation, 75% target scenario.

Figure 2 Household impacts of emissions targets: core scenarios

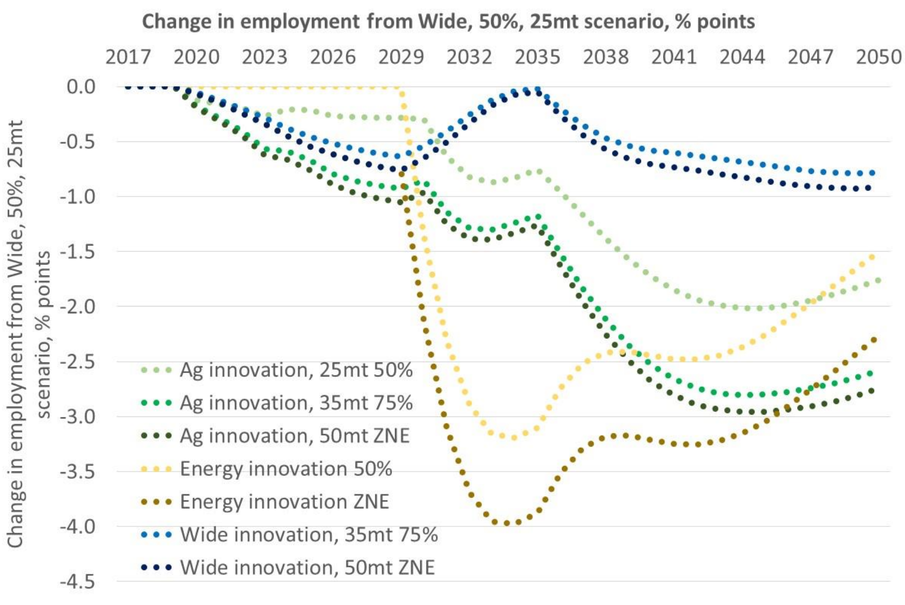
Change from 2050 status quo scenario per household RGNDI of $275,000



Source: NZIER

Figure 3 Impact on employment: core scenarios

% change from status quo



Source: NZIER

Lower income households are proportionately harder hit

Modelling carried out by our research partner, Infometrics, using a different CGE model, indicates that the impacts on households varies considerably by income level.

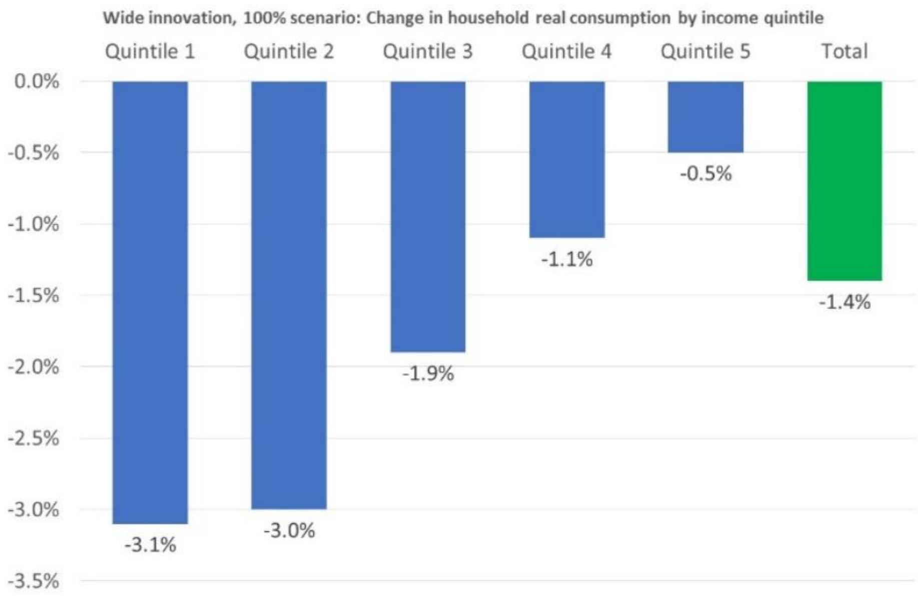
Figure 4 shows those in the lowest income quintiles (1, 2) are most severely affected – over twice as much as the average income household in relative terms.

While these household impacts may present challenges during the transition to a lower-emissions economy, the New Zealand Productivity Commission (2018, p.9) has recently noted that:

> *The adverse impact of such [price] increases on the real incomes of vulnerable households can be offset through the tax and welfare system.*
>
> *Existing policies, such as tax credits and benefits, should be adequate to compensate lower-income households for these increased costs, provided both are regularly adjusted in line with inflation.*

Figure 4 Impacts of Wide innovation ZNE target scenario on household spending, by income quintile

% change in real household consumption, relative to 2050 baseline[1]



Source: Infometrics

[1] NZIER's model does not have households broken down by income. Because of different model structures and specifications, the overall consumption decrease result estimated by Infometrics differs from our RGNDI per household impacts. What is more important here, however, is the *relative* impacts between income groupings, rather than the precise level.

Carbon prices will need to lift substantially to meet ambitious targets

The time profile of implied domestic carbon prices that the CGE model solves for under each combination of scenario and target is shown in Figure 5 and Figure 6.

The implied carbon price is best characterised as an economy-wide average price on firms' emissions. They will pay this price when it is lower than the cost of abating.

Before this point on their abatement cost curve, it makes more sense for firms to switch away from emissions-intensive inputs or production techniques.

If the government seeks to reduce emissions by regulations instead of via an emissions price, the implied price each firm will face depends on what the government does to share the cost burden. This would vary across industries. But since we don't know what measures the government may take, we simulate an economy-wide price.

The more stringent the emissions target, the higher the carbon price required to incentivise the behavioural changes necessary to move to a lower emissions economy (Table 4).

Table 4 Average implied carbon prices

Per tonne CO2-e, average between 2020-2050

Scenario	Ag	Ag	Ag	Energy	Energy	Wide	Wide	Wide
Target	**50%**	**75%**	**ZNE**	**50%**	**ZNE**	**50%**	**75%**	**ZNE**
Av carbon price	$386	$568	$605	$612	$845	$109	$243	$272

Source: NZIER

Prices are higher in the Energy innovation scenarios because they do not involve any additional net sequestration to the baseline. This forces the rest of the economy to move higher up its collective marginal abatement cost curve to meet any given emissions target. In addition, the Energy innovation scenarios do not include the methane vaccine.

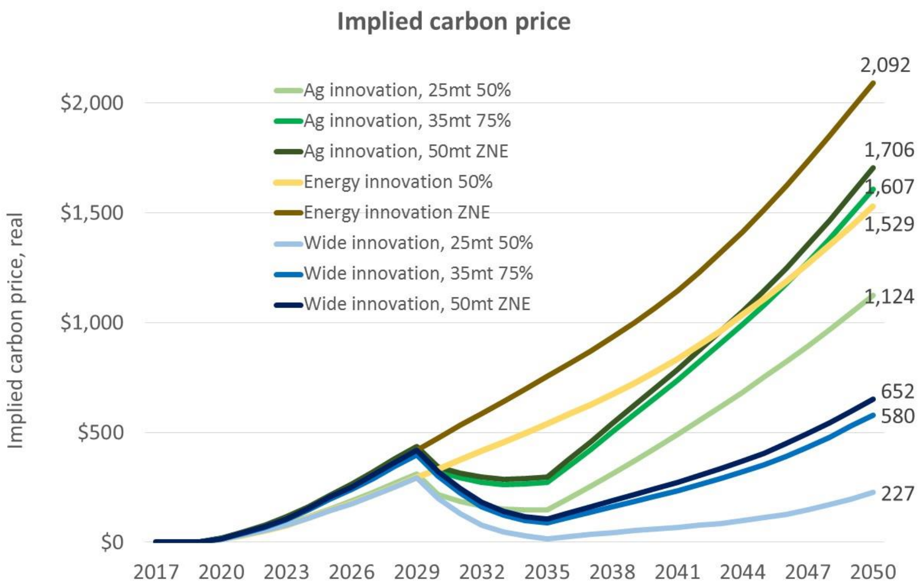
The impact of introducing the methane vaccine in 2030 in the Ag innovation and Wide innovation scenarios is noticeable. It makes abatement in New Zealand much less costly, and is a clear example of how innovation and R&D in emissions-reduction technologies will ease the burden of adjusting to climate change.

In the Ag and Wide innovation scenarios, the reduction in export demand for dairy and sheep and beef products also contributes to lower emissions (and hence lower implied carbon price).

We discuss the reasons for the differences between our implied carbon prices and those produced by Vivid, Motu and Concept (2018) below.

Figure 5 Implied carbon prices – levels

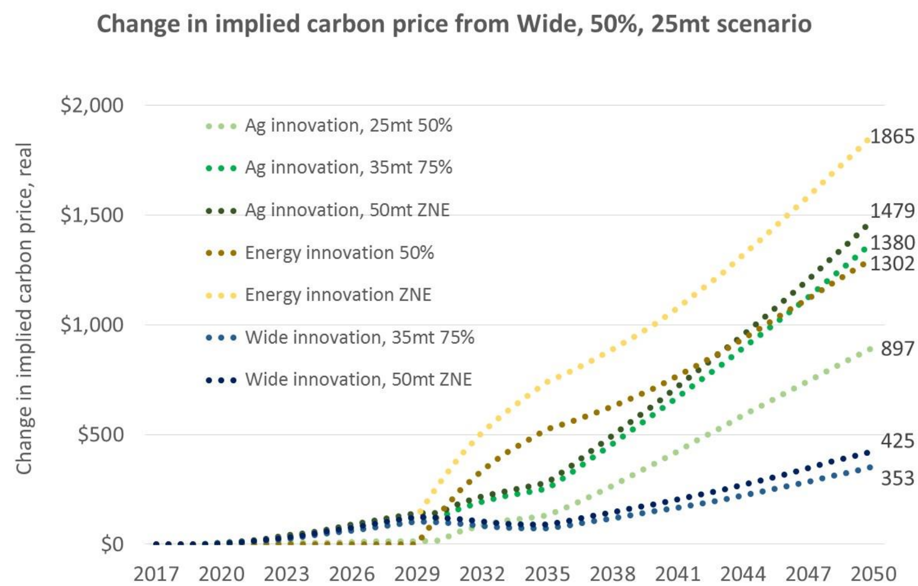
$ per tonne CO2-e



Source: NZIER

Figure 6 Implied carbon prices – differential from status quo

$ per tonne CO2-e, relative to status quo scenario



Source: NZIER

We also consider alternative specifications around the core Wide innovation, ZNE target scenario regarding rest of the world action on climate change, access to international permits and further net sequestration.

Sensitivity analysis: Free allocation remains crucial for limiting competitiveness impacts when the rest of the world does not take strong action to price carbon

We explore a scenario where the rest of the world does not take strong action on climate change. In this scenario, New Zealand imposes an emissions target and hence faces increasing carbon prices, while our competitors do not.[2]

At first glance, one might expect New Zealand to suffer a considerable loss in export competitiveness as our exporters face additional costs that their competitors don't.

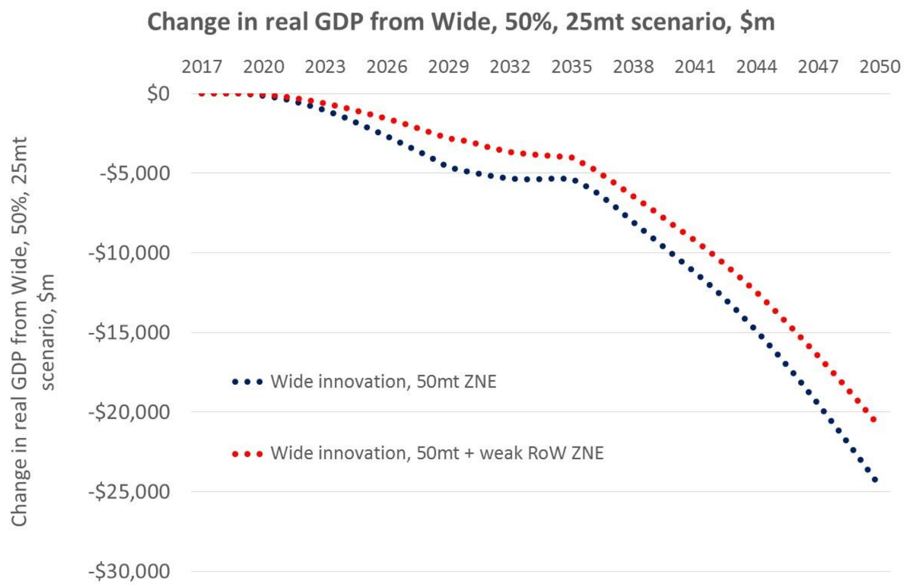
However, because we also assume that free allocation of emissions permits to emissions-intensive, trade-exposed firms continues at current rates, much of this competitiveness effect is mitigated.

The key macroeconomic impacts in this scenario are hence similar to that of the Wide innovation scenario with the same ZNE target. Aside from the implied carbon price, a weak rest of the world response that is mitigated by the continuation of free allocation very slightly reduces the economic costs of meeting an emissions target.

This highlights the importance of policy settings around free allocation when the actions of the rest of the world are uncertain.

Figure 7 Effects of weak global action on GDP impacts: Wide innovation scenario, ZNE target

$ millions change from status quo



Source: NZIER

[2] Future modelling will refine this scenario, as we will use a global CGE model that allows us to explore different countries taking different levels of action to address climate change. In the single-country model used for this report, it is not possible to design more nuanced scenarios – the rest of the world (as an aggregate) either takes strong action or it doesn't.

Table 5 Weak global action – summary of economic impacts

Change from status quo, 2050; ZNE target; SA = sensitivity analysis scenario

RoW action	Real GDP	Average GDP growth	Real GNDI per h/h	Employment	Real wage	Average carbon price
	% change, 2050	% 2017- 2050	$ change, 2050	% change, 2050	% change, 2050	2020-2050
Core (strong)	-4.9%	1.90%	-$13,600	-0.9%	-8.0%	$272
SA (weak)	-4.1%	1.93%	-$11,400	-0.8%	-7.3%	$283

Source: NZIER

Note that despite macroeconomic costs that are slightly lower when the rest of the World takes weak action, this should not taken as inferring New Zealand is better off if the rest of the World does nothing. Our single-country model does not capture the physical impacts of global climate change such as rising sea levels, the costs of infrastructure damage from more frequent/intensive storm events, etc.

Sensitivity analysis: Our forestry assumptions are critical in determining economic impacts

Of particular importance when interpreting the results in this report is the response of forestry to very high carbon prices.

In our model, forestry planting and harvesting is not linked to the carbon price directly. We have to impose net sequestration on our model rather than letting the model determine it. This is an important area for future model development.

We take our net sequestration estimates from Vivid, Concept and Motu (2018). Net sequestration in 2050 increases from 25Mt in the 50% target scenarios to 35Mt in the 75% target scenarios and 50Mt in the ZNE scenarios, to reflect the expected rough magnitude of the response of forest owners to the higher carbon prices that more stringent emissions targets would deliver.[3]

This level of afforestation is considerable. For example, the 50Mt scenario would see New Zealand's harvested forestry area increase by around 140% from today's area.[4]

However, when carbon prices are in the hundreds of dollars, the likely forestry response will be even larger than we have imposed on the model, provided there is suitable land available.

To demonstrate the effects of forestry, we consider the Wide innovation scenario for the 50%, 75% and ZNE targets with net sequestration constant at 40Mt. We compare the results against those from our core scenarios, where net sequestration is 25Mt, 35Mt and 50Mt respectively for the three targets.

As would be expected, for the 50% and 75% targets, a higher assumed rate of net sequestration reduces economic costs considerably (Figure 8 and Table 6):

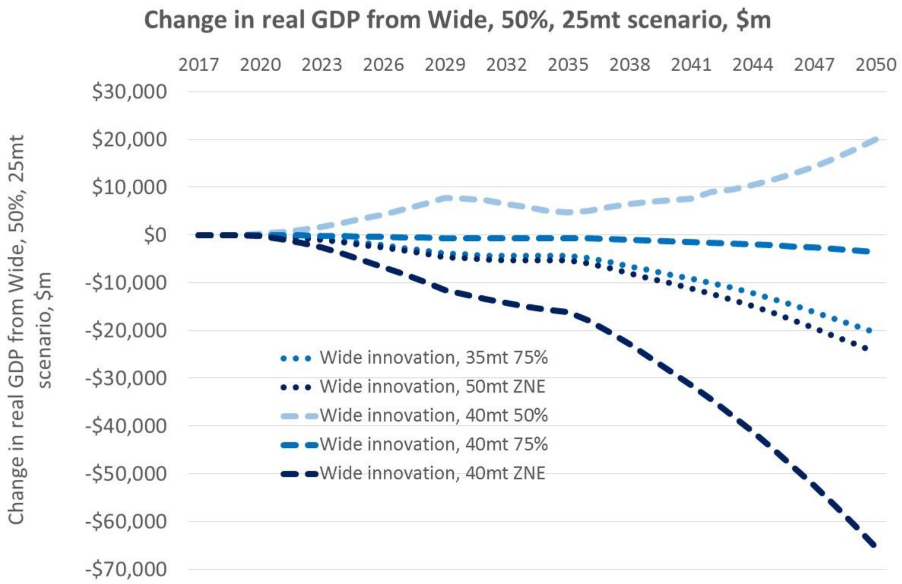
[3] We recognise that this is a simplistic approach. However, given time constraints, endogenising forestry's response to the carbon price was not feasible.

[4] Inferred from Motu (forthcoming).

- For the 50% target, using 40Mt of net sequestration instead of 25Mt shifts average annual economic growth between 2017 and 2050 from 2. 1% to 2.2%.
- For the ZNE target in this sensitivity analysis, assuming 40Mt of net sequestration instead of 50Mt in the core scenario pushes up economic costs significantly. The change in GDP below status quo in 2050 worsens from -4.9% in the core scenario to -12.9% in the sensitivity analysis.
- Average annual economic growth between 2017 and 2050 drops from 1.9% in the core ZNE scenario to 1.6% in the sensitivity analysis ZNE scenario. This could be thought of as reflecting potential environmental or societal challenges associated with planting and not harvesting the volume of trees required to abate 50Mt of CO2-e.
- The average implied carbon price from 2020 to 2050 falls as net sequestration increases. In the 75% scenarios, moving from 35Mt to 40Mt reduces the average carbon price from $243 to $131.[5]

Figure 8 The effect of alternative net sequestration assumptions on economic impacts

All results are for the Wide innovation scenario; $ millions change in real GDP from status quo



Source: NZIER

[5] Note that in the sensitivity analysis for a 50% target, there is so much net sequestration that the rest of the economy is not forced to abate anything more to reach the target. Hence there is no carbon price required.

Table 6 Alternative net sequestration sensitivity analysis – summary of economic impacts

Wide innovation scenario. Change from status quo, 2050; SA = sensitivity analysis scenario.

Target & net sequestration	Real GDP	Av GDP growth	Real GNDI per h/h	Employment	Real wage	Average carbon price
	% change, 2050	%, 2017-2050	$ change, 2050	% change, 2050	% change, 2050	2020-2050
SA (50%, 40Mt)	+3.9%	2.2%	+$11,000	+1.0%	+6.1%	-
Core (75%, 35Mt)	-4.0%	1.9%	-$11,300	-0.8%	-6.7%	$243
SA (75%, 40Mt)	-0.7%	2.0%	-$1,933	-0.2%	-1.2%	$131
Core (ZNE, 50Mt)	-4.9%	1.9%	-$13,600	-0.9%	-8.0%	$272
SA (ZNE, 40Mt)	-12.9%	1.6%	-$36,000	-2.3%	-20.1%	$569

Source: NZIER

Another interpretation of this sensitivity analysis is that it provides some insights into isolating the impact of changing the target, holding innovation and afforestation assumptions constant. In each of the sensitivity analysis (SA) scenarios in Table 6, net sequestration is held constant at 40Mt and the innovation assumptions do not change.

Moving from a 75% target to a ZNE target reduces average real GDP growth between 2017 and 2050 by 0.4% and reduces per household RGDNI by $34,100 in 2050.

Sensitivity analysis: access to international permits significantly reduces the economic impacts

In previous modelling exercises of New Zealand's climate change policy (see NZIER and Infometrics 2009, 2011), New Zealand firms had access to international emissions permits. When the cost of abating domestically was higher than the international permit price, firms bought permits to minimise costs.

In the core scenarios in this report, we assume no access to permits. We relax this assumption in this sensitivity analysis, using the Wide innovation, ZNE target as the comparator core scenario.

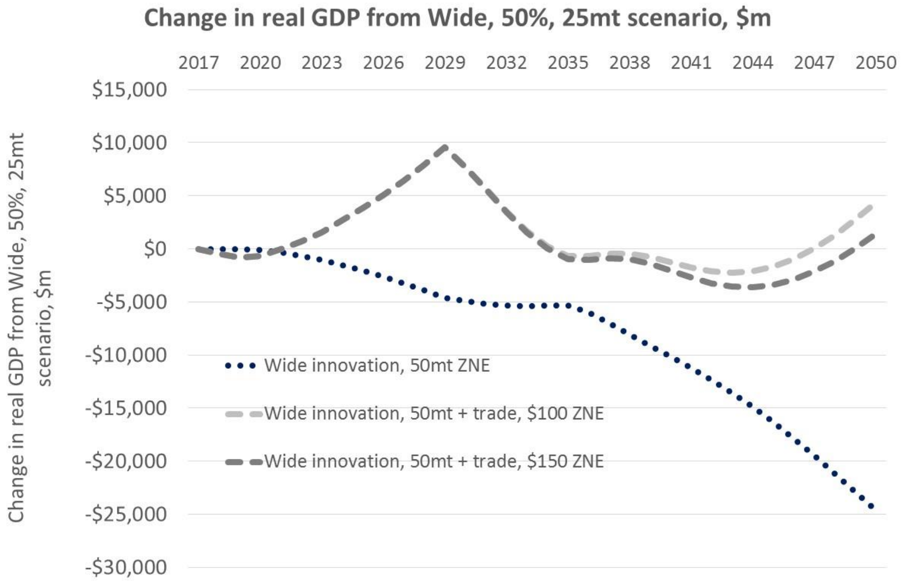
We assume, based on guidance from officials, two potential price paths for international permits:

- $20 today, rising linearly to $50 in 2030, then linearly to $100 by 2050.
- $20 today, rising linearly to $50 in 2030, then linearly to $150 by 2050.

The GDP impacts of allowing trading are shown in Figure 9. The economic costs of meeting a ZNE target fall sharply with permits trading. This is because firms choose to buy emissions permits from overseas rather than facing the high domestic abatement costs implied by imposing a stringent emissions target.

Figure 9 Sensitivity analysis: allowing international purchases of emissions permits

Change in $ millions from status quo; Wide innovation, ZNE target



Source: NZIER

Other results are summarised in Table 7. The economic costs are marginally higher when the international price is assumed to rise to $150 instead of $100, but both sensitivity analysis scenarios show significantly lower imposts on the economy than in the core scenario. Firms are able to avoid the high domestic abatement costs that occur in the core scenario when no trade is allowed.

Table 7 Permits trading sensitivity analysis – summary of economic impacts

Wide innovation scenario, ZNE target. Change from status quo, 2050; SA = sensitivity analysis scenario.

Target & net sequestration	Real GDP	Average GDP growth	Real GNDI per h/h	Employment	Real wage	Average carbon price
	% change, 2050	%, 2017-2050	$ change, 2050	% change, 2050	% change, 2050	2020-2050
Core (ZNE, 50Mt, no trade)	-4.9%	1.90%	-$13,600	-0.9%	-8.0%	$272
SA (ZNE%, 50Mt, trade, price path to $100)	+0.9%	2.08%	+$2,400	+0.9%	+0.7%	$60
SA (ZNE%, 50Mt, trade, price path to $150)	+0.3%	2.06%	+$800	+0.7%	-0.2%	$73

Source: NZIER

This sensitivity analysis demonstrates the importance of policy decisions related to access to international permits.

While abating all emissions domestically to meet a given 2050 emissions target is more consistent with a drive to a lower-emissions economy, allowing access to international permits allows New Zealand Inc to remove the same volume of emissions from the global atmosphere at a far lower economic cost.

Caution is required in interpreting our results

We note that at the very high carbon prices in some scenarios, it is difficult to be confident in how firms and households will respond. The implied changes in relative prices are well beyond the range over which our model has been calibrated.

For example, if someone gets a pay increase of $5,000, their previous patterns of consumption will give a good approximation of what they will spend this additional income on. Our model would work well here.

If that person wins $20 million on Lotto, however, they are likely to buy a very different bundle of goods and services, which would be hard to predict. Our model would be less useful here.

The same logic applies to carbon prices. If they go up 5%, we have a good idea of how households and firms will respond. If they go up 200%, it's hard to predict with certainty what choices people and businesses would make.

We estimate higher carbon prices than other research suggests…

These implied carbon prices are higher than those estimated by other researchers such as Vivid, Concept and Motu [VCM] (2018, p.4), who concluded that:

> *New Zealand is likely to be able to decarbonise its economy at a cost comparable to that expected in the rest of the developed world… reach[ing] a more stringent net zero emissions constraint by 2050 with a 2050 emissions price of between NZ$150/tCO2e to NZ$250/tCO2e.*

…due to different model purposes and structures

VCM's estimates were generated by linking a highly detailed energy and industry model with a detailed national scale, spatial, partial equilibrium model of rural land use. This modelling approach generates deep insights into how changes in economic incentives drive land use change, and how emitting sectors can meet demand at least cost (VCM, 2018, p.13).

As the authors of that study note (p.14), their bottom-up linked model focuses on "accurately depicting the incentives and outcomes within their specific sectors of focus. This means that while they provide a richness of detail that can be lacking in other models, they are unable to provide estimates of aggregate whole-of-New Zealand economic cost of different pathways".

That is, it will not produce macroeconomic results such as GDP, GNDI, employment, exports, etc., which is what we have been asked to focus on in this report.

VCM's modelling framework does not incorporate the types of constraints that a CGE model includes, such as those related to households' budgets, government spending, balance of payments, terms of trade, labour and capital constraints.

These constraints will tend to increase price changes relative to those generated by partial equilibrium models as there is no 'escape valve' in CGE models.

Another difference between the modelling approaches is that in VCM, "emission price trajectories in the period to 2030 are exogenously determined" (VCM, 2018, p.22). That is, in the early part of the projection period these prices are assumed, rather than being outputs of the models.

In contrast, in our CGE approach, the emissions price is *endogenously* determined in all years – we let the model solve for the emissions price, given a specific emissions target and a wide range of other assumptions.

Our models also incorporate different sets of assumptions. For example, the VCM modelling "pathways constrain the expansion of dairy farming, with no new land converted to dairying beyond 2025" (VCM, 2018, p.53). This will likely reduce dairy farming emissions, and hence reduce the required carbon price to meet a given 2050 target, relative to our approach, as we do not apply such a constraint.

None of this is to diminish the value of alternative modelling approaches. The VCM approach has considerably more detail on land use change than our model, and a much more granular representation of energy production, for example.

All models have strengths and weaknesses, and for policy issues such as climate change, there is considerable value in having a range of models to provide different insights into the main issues in play. The main strength of our approach, for this research objective, is that it generates whole-of-economy costs.

Structural change will be necessary to meet ambitious emissions targets

Our analysis of the industry impacts of meeting more ambitious 2050 emissions targets are consistent with the findings of the New Zealand Productivity Commission (2018, p. 10), which concluded that:

> *An effective transition to a low-emissions economy will mean that New Zealand will look very different in 2050. During the transition, action to mitigate GHG emissions will require real and significant changes. Those changes will have disruptive impacts on some businesses and households.*

Figure 10 shows the modelled changes in industry value-added (the industry equivalent of real GDP) for the Wide innovation, ZNE scenario.[6]

There are two key drivers of these results:

1. **The income effect** – as the economy grows less rapidly under scenarios with more ambitious emissions targets, there is lower demand for all goods and services.
2. **The substitution effect** – industries which are relatively low emissions-intensive face a lesser cost imposition from high carbon prices. This allows them to expand, or at least contract less than more emissions-intensive industries.

[6] For the sake of simplicity, we aggregate our database's 111 industries into 15 broader sectors for reporting these results. We need to acknowledge the risk of aggregation bias in doing so: within these broad sectors, some industries will be more affected; others less affected.

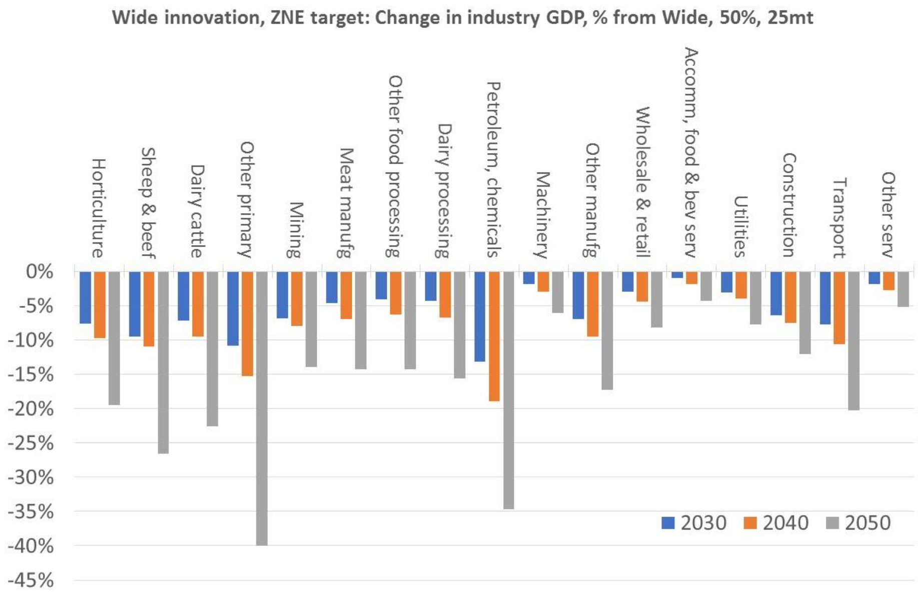
As would be expected, given the magnitude of carbon price increases required to meet a ZNE emissions target, the industries most affected are those that are emissions-intensive, such as dairy and sheep and beef farming, along with their downstream processing industries. The petroleum and chemicals sector also suffers significant negative adjustment.

Note that we do not model any potential change in government assistance to these most-affected industries.

The services sectors and some less emissions-intensive machinery and manufacturing are far less affected. Horticulture benefits (in relative terms at least) from our assumed shift in global consumer preferences away from dairy and meat towards lower-emissions foodstuffs.

Figure 10 Industry GDP impacts: wide innovation ZNE scenario

% change in industry value added from status quo in 2030, 2040, 2050



Source: NZIER

Similar patterns of structural change are found in all ZNE scenarios. The magnitude of change is lower with less stringent targets.

A more detailed industry disaggregation of the results shows that renewable energy generation industries (geothermal, hydro and wind) expand when emissions targets are imposed. There are also small gains for lower emissions-intensive manufacturing industries such as electrical equipment manufacturing and clothing manufacturing; and services industries such as accommodation, movies and rental services.

The forestry and wood processing industries will benefit

In addition, we would expect the forestry and wood processing industries to expand considerably if we modelled additional afforestation within the model, rather than imposing it exogenously.

In the Wide innovation, ZNE scenario, we assume an additional 50Mt of net sequestration by 2050. This would represent a 140% increase in the forested harvest area relative to the current area.[7]

Based on this expansion, an indicative out-of-model calculation suggests:

- The forestry industry would grow from $1.3 billion of value-added in 2017 to $3.1 billion in 2050 in the Wide innovation, ZNE scenario.
- The wood processing industry would grow from $1.3 billion in 2017 to $3.2 billion in 2050.
- Total log and processed wood exports would increase from $3.8 billion in 2017 to $9.1 billion in 2050.

Additional government support may be required to support workers who are negatively affected

These significant changes in the structure of the New Zealand economy may require further policy attention, especially if workers are dislocated from emissions-intensive industries. While our model allows labour to move between industries as they grow or contract, albeit with a lag, in practice there are challenges in doing so due to a lack of transferable skills between industries, geographical 'stickiness' of workers, etc.

Recall that we have not explored any specific government policies that could be used to ease the transitional costs to most-affected industries or households.

What next?

The scope of this stage of the analysis was necessarily limited due to time constraints. In the next phase of this research, we will seek to consider:

- Alternative scenarios that consider the actions of specific countries or groups of countries to address climate change concerns, and how this affects the economic impacts on New Zealand of meeting 2050 emissions targets.
- The economic costs of New Zealand inaction on climate change, such as changes to crop yields and the costs of infrastructure damage associated with more frequent or more intense storms.
- The regional economic impacts of meeting emissions targets.
- Different combinations of the various assumptions employed in this report, or alternative perspectives on innovation beyond those assumed in Table 1.

[7] This estimated increase in harvested area is inferred from Motu (forthcoming).

Contents

Appendices

Figures

Tables

1. Scope and objectives

1.1. Objectives

The task: estimate the economic impacts of meeting 2050 emissions targets

The Ministry for the Environment has commissioned NZIER, with assistance from Infometrics, to explore the economic impacts of New Zealand adopting a new 2050 emissions target.

We were asked to:

- consider a number of potential 2050 targets
- take into account expected and potential mitigation opportunities in New Zealand
- explore the distribution of economic impacts at the industry and household levels
- consider the implications of international developments to address climate change on New Zealand's export competitiveness and the wider economy.

This project comprises two workstreams. Workstream 1 focuses on the domestic aspects of climate change – what can New Zealand do to meet potential 2050 emissions targets? Workstream 2 will then explore the implications for New Zealand's economy of different degrees of other countries' action or inaction on climate change, as well as regional economic impacts.

This report covers only Workstream 1.

We use a dynamic CGE model to examine these economic impacts

We use a newly-developed dynamic Computable General Equilibrium (CGE) model of the New Zealand economy for Workstream 1. This single-country model contains economic and emissions projections to 2050 for 111 industries and 15 regions in New Zealand.

As noted in NZIER and Infometrics (2009, p. 3), "The most important advantage of CGE modelling is that it considers how policy shocks affect the allocation of resources between *all* sectors and markets in an economy. This is essential if we are to get a good macroeconomic understanding of how policy changes might affect the structure of an economy".

A CGE modelling approach is useful for comparing different scenarios about what may happen in the future, using a consistent theoretical framework and the same sets of data, parameters and assumptions.

We consider three core scenarios comprising a range of innovation and technology developments

We estimate the economic impacts of three core scenarios against three emissions targets. These economic impacts are compared against a status quo scenario to 2050 which incorporates policy settings that move New Zealand towards its current 2050 target (a 50% reduction from 1990 emissions).

The scenarios incorporate various types of innovation and technological change in the energy, transport and agriculture industries, along with additional net sequestration from the forestry sector (apart from in the Energy innovation scenarios).

There is no access to international emissions permits in any of these core scenarios. Therefore, all abatement to meet emissions targets has to occur domestically.

The scenario design was agreed with officials, and draws on – but is not identical to – the analysis in Vivid Economics, Concept and Motu's (2018) report to the New Zealand Productivity Commission as part of its enquiry into transitioning to a low-emissions economy.

We also consider three sensitivity analyses around the Wide innovation scenario to look at the impacts of:

- Access to international emissions permits, which allows firms to buy permits when their price is lower than their marginal cost of abatement.
- Weak global action on climate change, which raises questions of New Zealand's export competitiveness.
- Alternative net sequestration assumptions to those in the core scenarios.

Table 8 Overview of scenarios

Scenario name	Key features
Baseline	Current policy settings and energy efficiency trends; biological emissions excluded; $20 carbon price; strong rest of world action on climate change; phase out of free allocation; EV uptake of 65% of light vehicle fleet by 2050; no access to international permits.
Core scenarios	
Ag innovation	Biological emissions included; methane vaccine introduced in 2030, reducing biological emissions by 30%; lower global demand for dairy and meat exports; expansion of horticulture; large expansion in net sequestration.
Energy innovation	Biological emissions included; widespread, more rapid energy efficiency improvements; EV uptake to 95% of light vehicle fleet and 50% of heavy vehicle fleet; 98% renewable electricity from 2035. No additional net sequestration above the baseline.
Wide innovation	All measures in Ag and Energy innovation scenarios combined.
Sensitivity analysis	
Wide innovation + trade	Wide innovation plus access to international permits which increase in price from $20 now to $50 by 2030 and either $100 or $150 by 2050.
Wide innovation + weak RoW	Wide innovation but global response to climate change is weak; New Zealand exporters face competitiveness challenges; free allocation held steady.
Wide innovation, alternative forestry	Wide innovation for 50% and 75% targets that incorporates higher net sequestration (40Mt) than in core scenarios; wide innovation for ZNE target with lower net sequestration (40Mt) than in core scenario.

Source: NZIER

These scenarios are not our predictions of the future

We do not comment on the likelihood of any of these innovation and technological changes occurring. Essentially, we take these assumptions as given, and use our CGE model to examine their economic impacts.

Our CGE model "does not predict what *will* happen in the future. Rather, it is an assessment of what *could* happen in the future, given the structure of the model and input assumptions" (Australian Treasury, 2008, p.16, emphasis added).

We have not estimated the costs of introducing emissions-reducing technologies

In our scenarios, we have not attempted to determine who pays for the various innovations, or when these costs might be incurred. We assume, for example, a methane vaccine simply becomes available in 2030 and that faster EV uptake occurs without government subsidies.

We recognise this is not ideal, but such an exercise was not feasible given time and resource constraints. There is also a lack of suitable information available on these costs.

We model 2050 targets that increase in ambition from 50% to 100% of 1990 gross emissions

These scenarios are assessed against a range of potential emissions targets, which reflect different levels of ambition:

1. 100% reduction on 1990 gross levels by 2050 (henceforth 'zero net emissions' or ZNE)
2. 75% reduction on 1990 gross levels by 2050
3. Existing target of 50% reduction on 1990 gross levels by 2050.

These targets are approached using the gross-net methodology. That is:

- We start with 1990 gross emissions of 64.6Mt
- We determine the 50/75/ZNE reduction in emissions by 2050 from this starting point
- We subtract expected forestry sequestration to give us the maximum permissible gross emissions in 2050 after having accounted for the effects of forestry in meeting each target
- We compare this against the 2050 baseline gross emissions estimate to determine the reductions required to hit each 2050 target.

Our model estimates the economic impacts at the macroeconomic level (GDP, Gross National Disposable Income, employment, real wages, exports, etc.) and industry level.

We draw on Infometrics' ESSAM CGE model to provide insights into the household distributional effects of introducing a 2050 emissions target.

1.2. Scope and caveats

We are confident that our dynamic CGE model is a reasonable representation of the New Zealand economy and its emissions profile out to 2050, based on currently available information.

However, as with any modelling exercise, there are several limitations that need to be acknowledged (also see NZIER and Infometrics, 2009, pp. 3-6):

1. Projecting the economy out to 2050 is inherently challenging. There are untold possibilities for structural changes in the global and New Zealand economies that cannot reasonably be predicted in 2018. We state the assumptions behind our economic projections very clearly, and alternative sets of projections could be examined in future work.

2. Since they represent the inner workings of an entire economy, rather than one sector, CGE models depend on many data sources, parameters, equations and assumptions. It is not practical to explore the effects of changing all of these parameters and assumptions, although this can be done with more time and resources.

3. CGE models' *ex ante* estimates of the economic impact of policy changes are rarely 'validated' against actual *ex-post* outcomes. This makes it difficult to know how accurate they are.

4. The economic theory underpinning CGE models is usually neoclassical in nature. Consumers maximise utility, firms minimise costs, resources can move between sectors, and firms do not generate super-normal profits. These assumptions can quite legitimately be questioned, and alternative theoretical specifications are entirely feasible in a CGE modelling framework if they are judged to be superior.

5. CGE models cannot predict if or when disruptive technological changes, such as a methane vaccine, may occur. The modeller has to design scenarios that introduce such change into the model. These scenarios allow the modeller to ask "What if…?" questions of the model.

6. Similarly, if a new industry develops in the future – say space travel – our CGE model will not capture it unless we as modellers tell it to.

7. Our model cannot predict how global consumer preferences might adjust in response to concerns over climate change. For example, if consumers decide to eat plant-based meat alternatives instead of actual meat due to concerns over the environmental footprint of pastoral farming, our model cannot foresee this coming.[8]

8. Our CGE model does not incorporate endogenous technical change. That is, innovation is not directly linked to the carbon price. In reality, we

[8] Note, however, that there <u>are</u> preference parameters in the modelling framework, but they are exogenous – they don't change unless we tell them to.

would expect innovation and technological change to respond to the carbon price. The higher the carbon price in an economy, the greater the incentive firms and households have to invest in avoiding high-emissions activities. This is an area for future research, and is discussed further in section 3.2.

9. At this stage, forestry net emissions are imposed exogenously on the model, rather than planting and harvesting behaviour being determined by the carbon price. Note there is no additional net sequestration to the baseline in the Energy innovation scenarios.

10. Additional net afforestation will lead to an expansion of the forestry and downstream wood processing industries. However, because we impose net sequestration on the model exogenously, rather than asking the forestry industry to grow within the model, our scenarios do not capture this expansion. The modelled GDP and export results for forestry and downstream sectors are therefore significantly understated, given the anticipated surge in afforestation as carbon prices increase in response to emissions targets.

    We provide an indicative estimate of the potential growth of the forestry and wood processing industries in an out-of-model calculation in this report. We will seek to address this issue further in the next stage of this research.

11. We assume that additional forestry planting does not materially reduce the amount of productive land available for other uses. This could be seen as assuming that additional planting occurs on scrub land, rather than substituting for sheep and beef or dairy land.

    If afforestation occurs on productive land, the economic costs of imposing emissions targets will increase, as the productive capacity of the agricultural and horticultural industries will decrease, which will also have negative flow-on effects for downstream primary processing industries.

12. We do not consider in this workstream the physical impacts of climate change on the New Zealand economy, such as rising sea levels, changes to crop yields, increased incidence of severe drought, etc. This will be explored in Workstream 2, however.

13. Neither do we consider potential co-benefits of climate change mitigation policies, such as water quality improvements. These impacts would reduce the net costs of imposing emissions targets on the New Zealand economy.

Our CGE modelling results should be seen as part of the evidence base to inform decision-makers, rather than its entirety

These caveats do not mean that our modelling results are not robust. Rather, they reflect the inherent challenges in carrying out economic and climate change modelling work over a 30+ year timeframe, with limited available time and resources.

They also reflect the fact that no single economic model can realistically hope to answer all potential climate change policy research questions.

However, we hope that our approach draws out some of the costs, benefits and trade-offs associated with introducing different emissions targets in New Zealand.

We have sought to be as transparent as possible about our methodology, data and assumptions; and their limitations. Any number of alternative potential modelling scenarios could be considered with additional time and resources.

Given the importance of the subject, a range of tools and techniques will be required to paint a fuller picture of New Zealand's options, opportunities and challenges in responding to climate change. Our results should be seen as just one part of the evidence base that will inform policy advice on climate change policy in New Zealand.

2. Overview of methodology

We develop a single country dynamic Computable General Equilibrium (CGE) model, Monash-New Zealand-Green (MNZG) for exploring the economic impacts of meeting different 2050 emissions targets.

For an overview of CGE modelling of climate change policies and its strengths and weaknesses, see section 3.2 of NZIER and Infometrics (2009).

MNZG is based on the Monash-New Zealand dynamic CGE model, augmented to include greenhouse gases associated with economic activity.[9]

2.1. Monash-New Zealand model

CGE models: the basics

A CGE model consists of equations which describes model variables. It also uses detailed data on the structure of the economy that is consistent with these model equations.

This data provides a snapshot of the economy in a particular year, which is used as a starting point for a baseline (or BAU) against which to compare policy simulations or economic changes.

The model data is linked together through a set of equations which capture how the economy evolves over time in response to a shock. These equations, which are based on the economic theory of general equilibrium, ensure supply and demand for goods, services and factors of production in the economy are balanced, and determine how firms and households react in response to changes in the relative prices of factors of production and intermediate inputs.

Most CGE models are written and solved in a specific software system, usually GAMS[10] or (in our case) GEMPACK.[11]

In any CGE model, we must choose as to what is to be determined within the model (the endogenous variables) and what is to be considered external to the model (the exogenous variables). A CGE model explains the endogenous variables in terms of the exogenous variables.

Where we draw the line between endogenous and exogenous variables, and which ones can vary or have to remain fixed, depends on a number of factors, including the purpose for which the model simulations are to be used. The choice that we make is called the model 'closure'.

9 NZIER's suite of CGE models, including the Monash-New Zealand version, are based on those developed by the Centre of Policy Studies (COPS), previously at Monash University and now at Victoria University, Melbourne. They have been tailored for New Zealand research by NZIER staff members who have also worked at COPS. COPS's model are used by over 400 organisations in over 60 countries (see https://www.vu.edu.au/centre-of-policy-studies-cops/about-the-centre).

10 General Algebraic Modelling System: https://www.gams.com/

11 General Equilibrium Modelling PACKage: https://www.copsmodels.com/gempack.htm

The difference between the initial and the post-shock equilibrium can then be analysed to determine the effect of the shock on a range of economic indicators, such as GDP, employment, wages and welfare.

Our CGE model contains details on 111 industries

NZIER's Monash-New Zealand dynamic CGE model represents the New Zealand economy and contains information on 111 industries and 201 commodities in its basic form. We aggregate these industries for the purpose of simplifying the reporting of industry results.

The economic database on which the model draws is sourced initially from Statistics New Zealand's 2013 Inter-Industry tables (Statistics New Zealand, 2016), although we expand its 106 industries by adding more detail on electricity generation.

We project the economy out to 2050 for our baseline scenario

We project the model baseline out to 2050 using NZIER's *Quarterly Predictions* macroeconomic forecasts out to 2022, and longer-term projections of labour productivity and employment, exports and import growth, investment and GDP growth, terms of trade, and inflation.

See Appendix A.2 for more detail on the economic baseline to 2050.

The model captures the various inter-linkages between the 111 industries, as well as their links to households (via the labour market), the government sector, capital markets and the global economy (via imports and exports).

We incorporate six forms of electricity generation

The underlying database also captures energy use inputs by each industry. Energy use, along with labour and capital, enter each industry's production structure through a Constant Elasticity of Substitution nest.

Our database incorporates six electricity generation methods: coal, oil, gas, hydro, geothermal, and wind.

Dynamic features allow us to see how the economy adjusts out to 2050

Dynamic models allow the user to examine changes to the economy due to shocks such as targeting emissions over time, and to see how key variables respond as the economy returns to its long run growth path.

Previous CGE modelling of climate change policies in New Zealand has relied primarily[12] on *static* CGE models that compare the 'before' policy economy with the 'after' policy economy, with no analysis of the transition between these two points in time. Our dynamic model allows us to explore this transition path.

The dynamic features of the model are based on the Australian version of the MONASH model, now known as 'VU-National'.

The dynamic features include:

[12] The exception being Landcare Research's 2015 work on New Zealand's INDC.

- **Labour market adjustment** – we allow both wages and employment to vary, whereas in a static modelling approach one of these must be held constant.
- **A capital accumulation mechanism** to allow investment to respond to changes in rates of return by industry.
- **Changes in the current account and capital account** over time, which can be used to explore the effects of overseas borrowing and debt repayment.

A technical description of the model is provided in Dixon and Rimmer (2002).

2.2. Incorporating emissions into Monash-New Zealand

To make the Monash-New Zealand model fit for purpose for this project, we needed to build greenhouse gas emissions into our database, so that when the economy adjusts in response to a policy or technological change (or 'shock' in CGE vernacular), the output and emissions produced by each industry also adjust.

We used emissions data from New Zealand's 7th National Communication[13] to the UNFCCC and Statistics New Zealand (2018) to update our database, along with updated emissions estimates out to 2050 that have been prepared by various government agencies, including:

- Projections of the forestry sector's net emissions from MPI.
- Projections of emissions by key agricultural industries from the Ministry for Primary Industries (MPI).
- Projections of road transport emissions and Electric Vehicle (EV) uptake from the Ministry of Transport (MoT).
- Estimates of potential energy efficiency improvements in the residential, commercial and industrial sectors from the Energy Efficiency and Conservation Authority (EECA).
- Projected energy mix and associated emissions from the Ministry of Business, Employment and Innovation (MBIE).

We take into account all greenhouse gases, but the emissions data are expressed in CO2-e.

We call the resulting dynamic CGE model, now with emissions incorporated, Monash-New Zealand-Green or MNZG.

[13] Note our baseline was finalised prior to the release of New Zealand's Greenhouse Gas Inventory 1990–2016. The differences between our baseline and the inventory are small and will not have a material impact on our modelling results.

3. Scenario design and targets

3.1. Scenario description

Table 9 summarises the key features of the scenarios modelled.[14]

Table 9 Scenario description

Scenario name	Description and modelling approach
Baseline	As described in Appendix A.
Core scenarios	
Ag innovation	- Emissions targets imposed. Model solves for implied carbon price to meet targets. - Biological emissions priced. - Methane vaccine introduced in 2030, reducing dairy emissions by 30% and S&B emissions by 20%; 100% adoption. - Reduction in global demand for dairy (-11% fall in 2050 output from 2015 levels) and S&B (-15%) as consumer preferences shift towards lower emissions-intensive foodstuffs. - Expansion of low-emissions horticulture sector in response to this change in global preferences. We let the model determine horticulture expansion as it substitutes for dairy and S&B. - Model solves for carbon price to reduce domestic emissions to target. - Sequestration assumptions: o 50% target: 25Mt by 2050 o 75% target: 35Mt o ZNE target: 50Mt.
Energy innovation	- Emissions targets imposed. Model solves for implied carbon price to meet targets. - Biological emissions priced. - Double the baseline energy efficiency trends applied across all industries to proxy broad and rapid technological change. - Increase EV uptake to 95% of light vehicle fleet and 50% of the heavy vehicle fleet by 2050. - Move to 98% renewable electricity by 2035 and held constant out to 2050. Remaining 2% will be gas, to be used in dry years. - All other assumptions as per baseline, including net sequestration.
Wide innovation	Ag and Energy innovation scenarios together.
Sensitivity analysis	
Wide innovation + trade	As for Wide innovation scenario plus access to international permits.
Wide innovation + weak ROW	As for Wide innovation scenario, but assume ROW action is weak. Terms of trade allowed to vary to reflect loss of New Zealand export competitiveness. Free allocation held steady at 2016 levels.
Wide innovation, alternative forestry	Wide innovation for 50% and 75% targets that incorporates higher net sequestration (40Mt) than in core scenarios (25Mt and 35Mt respectively). Wide innovation for ZNE target with 40Mt net sequestration instead of 50Mt.

Source: NZIER

[14] We drew on Vivid Economics, Concept and Motu (2018) to inform our scenarios, though do not try to replicate them.

3.2. What level of innovation is right?

Our model does not incorporate 'endogenous technological change'. That means innovation does not respond to the higher carbon prices associated with imposing an emissions target *within the model itself*.[15] Instead, we need to impose assumptions about innovation on the model through our scenario design.

The same applies for the response of forestry owners to higher carbon prices. Our model cannot predict the extent of new planting or avoided harvesting as carbon process rise. We have to make choices about this response outside of the model, and build them into our scenario design.

In reality, all discussions about innovation will be conditional on the expected carbon price. That is, any judgement about technological change or afforestation needs to made with an eye on the carbon prices that are expected to prevail.

If you look at the innovation assumptions in Table 9 relative to current, low carbon prices, they look optimistic.

But if – as our modelling indicates – carbon prices will rise substantially to incentivise firms to move towards lower-emissions production techniques that are consistent with ambitious emissions targets, then some assumptions we have used might be considered conservative.

We simply don't know how firms, forest owners and households would change their production and consumption behaviour in a high-, or very high-, carbon price economy. We don't know the types of new technologies or new industries that would emerge if carbon prices were in the hundreds of dollars. We don't know how commuters would respond to petrol prices that are a multiple of today's prices.

We recognise these limitations to our analysis, but ultimately we have to assume something, even if we know it's unlikely to be a perfect approximation of economic agents' behaviour.

3.3. Targets to be assessed

These scenarios are assessed against a range of potential emissions targets, which reflect different levels of ambition:

1. 100% reduction on 1990 gross levels by 2050, or zero net emissions (**ZNE**)
2. 75% reduction on 1990 gross levels by 2050 (**75%**)
3. Existing target of 50% reduction on 1990 gross levels by 2050 (**50%**).

These targets are approached using the gross-net methodology. That is:

- We start with 1990 gross emissions of 64.6Mt[16] (column 1 in Table 10) below.
- We determine the 50/75/ZNE reduction in emissions by 2050 from this starting point (columns 2 and 3).

[15] See Dechezlepretre et al (2013, 2016) for empirical evidence of how innovation responds positively to stronger climate change policy actions.

[16] See Ministry for the Environment (2017, p.xxiii).

- We subtract forestry sequestration (column 4) to give us the maximum permissible gross emissions in 2050 after having accounted for the effects of forestry in meeting each target (column 5).
- We compare this against the baseline gross emissions estimate to determine the reductions required to hit each target (columns 6 and 7).

Table 10 Overview of targets in core scenarios

1	2	3	4	5	6	7
1990 gross emissions	% cut from 1990 gross emissions	Cut from 1990 gross emissions	Forestry sequestrati on	2050 target	Cut from 2050 gross baseline of 87.0Mt	% cut from 2050 gross baseline
64.6Mt	50%	32.3Mt	-25Mt	57.3Mt	29.8Mt	34%
64.6Mt	75%	48.5Mt	-35Mt	51.1Mt	35.9Mt	41%
64.6Mt	100% (ZNE)	64.6Mt	-50Mt	50.0Mt	37.0Mt	43%

Source: NZIER

Note that the cut from 2050 baseline percentages in column 7 are similar for the 75% and ZNE scenarios (from 41% cut to 43% cut), whereas the difference between the 50% and 75% cuts is much larger (from 34% to 41%).

This is due to the forestry assumptions employed. When we move from a 75% target to a ZNE target, we assume an extra 15Mt of net sequestration (from 35Mt to 50Mt). The corresponding figure between a 50% target and a 75% target is only 10Mt (from 25Mt to 35Mt).

Further combinations of scenarios and targets can be considered in future research.

We impose these emissions targets on the model in a linear fashion between 2020 and 2050. We do not attempt to force the model to hit existing 2030 emissions targets, as it is the 2050 targets that are the focus of this research.

4. Results

4.1. The choice of counterfactual is important

This analysis aims to support officials' regulatory impact analysis on potential regulatory changes to move the New Zealand economy towards a ZNE target by 2050.

Such analysis needs to report on the marginal costs, benefits and trade-offs in moving from the status quo (what would happen in the absence of regulatory change) to an alternative package of regulatory measures.

Therefore, we need to decide the status quo against which our scenario results should be compared. There are two main options here:

1. Compare scenario results against the **baseline** 'do-nothing' scenario. While this is the traditional approach in CGE modelling, in this report the baseline does not adequately capture the likely policy direction required to move the New Zealand economy to its existing 2050 emissions target of a 50% cut on 1990 levels.

   Therefore, comparing against the baseline will likely over-estimate the *marginal* costs of the scenarios over and above the status quo.

2. Compare against a counterfactual **status quo** that better reflects the likely policy settings needed to meet New Zealand's existing 2050 target. Taking this approach better captures marginal changes for regulatory impact analysis, but does not explicitly recognise the costs of transitioning the economy from its current pathway to a pathway that meets a 50% emissions reduction by 2050.

   Therefore, comparing the scenario results solely against a 50% emissions target status quo will under-estimate the *total* costs from moving from today's economic structure to a lower-emissions future.

We therefore present the results in two steps. The first step shows the estimated economic impacts of moving from the current state to a 50% emissions reduction target scenario. The second step, which we use for the bulk of the results reporting in this report, shows the marginal economic impacts over and above this 50% target status quo.

Based on guidance from officials, we refer to the Wide innovation, 50% target as the status quo in this report.

To the extent that this status quo is overly ambitious, then the marginal economic impacts we report in section 4.3 onwards will be under-stated.

4.2. Economic impacts of getting to the status quo

As a recap, the assumptions in the Wide innovation, 50% target scenario are as follows:

- Biological emissions are priced.
- Methane vaccine introduced in 2030, reducing dairy emissions by 30% and S&B emissions by 20%; 100% adoption.
- Reduction in global demand for dairy and sheep and beef as consumer preferences shift towards lower emissions-intensive foodstuffs.
- Expansion of low-emissions horticulture sector in response to this change in global preferences.
- Net sequestration assumption: 25Mt by 2050
- Double the baseline energy efficiency trends applied across all industries to proxy broad and rapid technological change.
- EV uptake to 95% of light vehicle fleet and 50% of the heavy vehicle fleet by 2050.
- Move to 98% renewable electricity by 2035 and held constant out to 2050.

Therefore, this status quo incorporates a considerable amount of innovation and afforestation. However, given the relatively high carbon prices that our modelling delivers when we impose ambitious emissions targets, such changes from the situation today are probably not unreasonable.

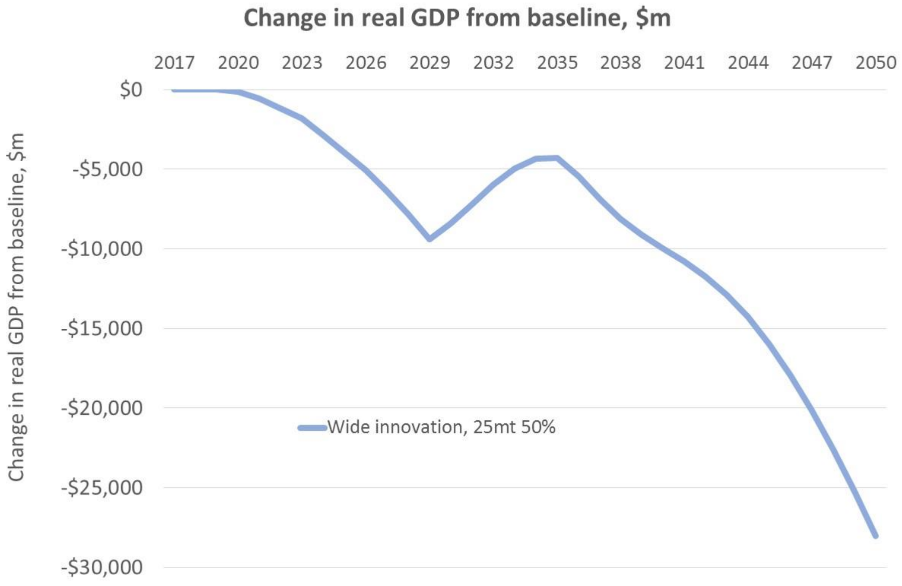
Our modelling suggests that there will be significant costs involved in getting from a baseline 'do nothing' scenario to this Wide innovation, 50% target status quo (Figure 11).

We estimate real GDP in the status quo to be $28.0 billion (5.2%) lower than baseline by 2050. On an annual average basis between 2017 and 2050, real GDP will fall by $8.6 billion from $386.0 billion in the baseline to $377.4 billion in the status quo.

The two kinks in the chart reflect the impact of the methane vaccine that is introduced in 2030 and gradually rolled out across all dairy and sheep and beef farms to 2035. This gives the economy a temporary boost (or at least, less of a negative shock) as it lifts on-farm productivity. After 2035, the GDP impact returns back to its pre-vaccine downward trend.

Figure 11 Economic impact of getting to the status quo of a 50% emissions reduction target by 2050

Change in real GDP, $ millions, compared to baseline



Source: NZIER

Employment will be 1.2% and real wages 6.1% below baseline by 2050. The costs to households, in terms of reduced RGNDI, will be $15,700 per household by 2050. This equates to over $1,400 per household per year in today's money.

The marginal impacts reported on below need to be seen as additional to these costs.

We first present the results for the core scenarios. The results for the sensitivity analysis follow.

4.3. Core scenarios: National GDP impacts

Under the core scenarios, real GDP will be between $24.6 billion (4.9%) and $85.1 billion (16.8%) lower than status quo by 2050 for the ZNE targets (see Table 11, Table 12, and Figure 12).

As the emissions target reduces to 75%, the GDP costs range between $20.5 billion (4%) and $63.2 billion (12.5%).

On an annual average basis, real GDP drops by between $6.7 billion and $26.6 billion in the ZNE scenarios, from $377 billion between 2017 and 2050 in the status quo (Table 13).

The corresponding changes from the 'do nothing' baseline are also presented to give an indication of the total costs of moving from today's economy to the emissions reduction target scenarios. The real GDP cost of meeting ZNE targets is between $52.7 billion (9.9%) and $113.2 billion (21.2%) below baseline by 2050.

Table 11 GDP impacts in 2050 – levels

$, compared to **baseline** of $534 billion in 2050

Scenario	50% target	75% target	ZNE target
Ag innovation	-$66.4 bn	-$91.2 bn	-$96.0 bn
Energy innovation	-$85.7 bn	Not modelled	-$113.2 bn
Wide innovation	- $28.0 bn	-$48.5 bn	-$52.7 bn

$, compared to **status quo** of $506 billion in 2050

Scenario	50% target	75% target	ZNE target
Ag innovation	-$38.4 bn	-$63.2 bn	-$67.9 bn
Energy innovation	-$57.7 bn	Not modelled	-$85.1 bn
Wide innovation	-	-$20.5 bn	-$24.6 bn

Table 12 GDP impacts in 2050 – %

% change from **baseline** of $534 billion

Scenario	50% target	75% target	ZNE target
Ag innovation	-12.4%	-17.1%	-18.0%
Energy innovation	-16.0%	Not modelled	-21.2%
Wide innovation	-5.2%	-9.1%	-9.9%

% change from **status quo** of $506 billion

Scenario	50% target	75% target	ZNE target
Ag innovation	-7.6%	-12.5%	-13.4%
Energy innovation	-11.4%	Not modelled	-16.8%
Wide innovation	-	-4.0%	-4.9%

Table 13 GDP impacts – annual averages

$ change, compared to **baseline** annual average real GDP of $386 billion, 2017-2050

Scenario	50% target	75% target	ZNE target
Ag innovation	-$19.1 bn	-$27.4 bn	-$29.0 bn
Energy innovation	-$27.0 bn	Not modelled	-$36.9 bn
Wide innovation	-$8.6 bn	-$15.1 bn	-$16.5 bn

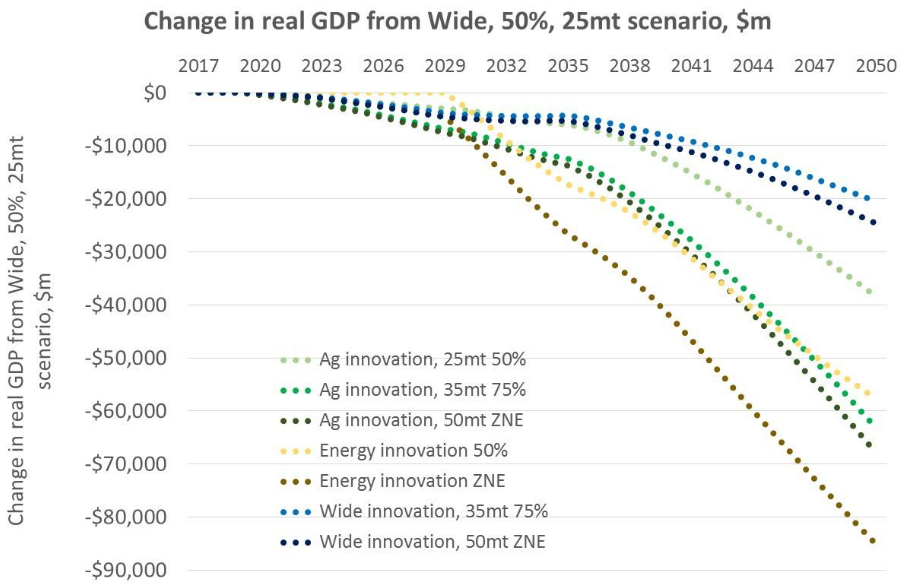
$ change, compared to status quo annual average real GDP of $377 billion, 2017-2050

Scenario	50% target	75% target	ZNE target
Ag innovation	-$9.3 bn	-$16.9 bn	-$18.9 bn
Energy innovation	-$16.7 bn	Not modelled	-$26.6bn
Wide innovation	-	-$5.9 bn	-$6.7 bn

Source: NZIER

Figure 12 GDP impacts in 2050 against status quo – levels

$, compared to status quo of $506 billion in 2050



Source: NZIER

4.3.1. The economy continues to grow

Table 14 GDP indicators

Scenario	Baseline	Ag	Ag	Ag	Energy	Energy	Wide	Wide	Wide
Target	**-**	**50%**	**75%**	**ZNE**	**50%**	**ZNE**	**50%**	**75%**	**ZNE**
Average GDP per year, $bn, 2017-2050	$386	$367	$359	$357	$359	$349	$377	$371	$370
Average GDP growth rate, 2017-2050	2.2%	1.8%	1.6%	1.6%	1.7%	1.5%	2.1%	1.9%	1.9%
Difference in av. growth rate from status quo	+0.17%	-0.24%	-0.41%	-0.44%	-0.37%	-0.57%	-	-0.13%	-0.15%
Difference in av. growth rate from baseline	-	-0.41%	-0.58%	-0.61%	-0.54%	-0.73%	-0.17%	-0.29%	-0.32%

Source: NZIER

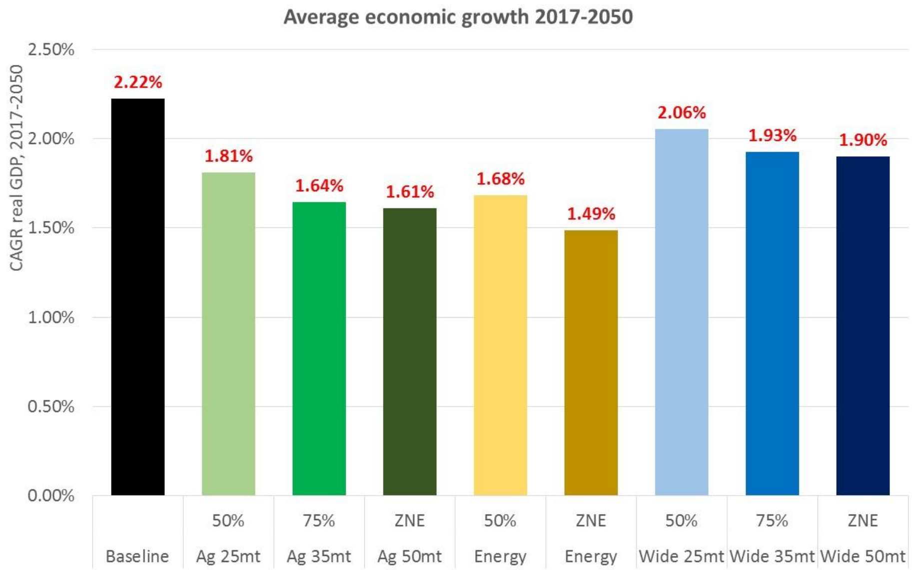
It is important to note that under all core scenarios and targets, the economy continues to expand (Table 14, Figure 13):

- In the Ag innovation scenarios, growth averages 1.6% to 1.8% between 2017 and 2050.
- In the Energy innovation scenarios, growth averages 1.5% to 1.7%
- In the Wide innovation scenarios, growth averages 1.9% to 2.1%.

These rates compare to baseline average economic growth between 2017 and 2050 of 2.2%. Across the core scenarios, the difference between the ZNE target average growth rates and the 50% target growth rates is around -0.2%.

Figure 13 Average economic growth, 2017-2050

Compound Annual Growth Rate of real GDP

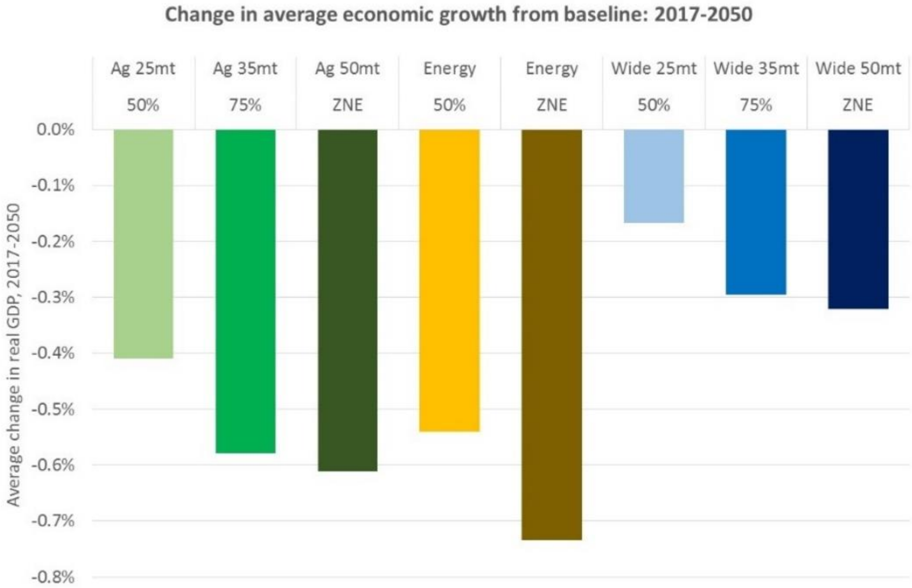


Source: NZIER

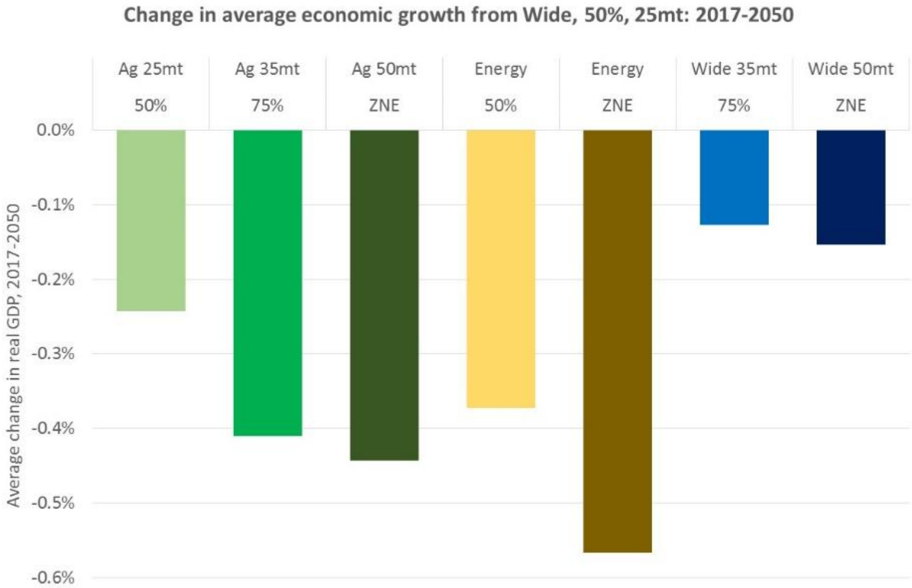
Figure 14 overleaf shows the *difference* between average GDP growth rates in the scenarios relative to the 2.2% in the baseline and also the 2.1% for the status quo scenario (Wide innovation, 50% target).

Figure 14 GDP growth differentials from baseline and status quo

Compound Annual Growth Rate of real GDP relative to baseline



Compound Annual Growth Rate of real GDP relative to status quo



Source: NZIER

4.4. Household impacts

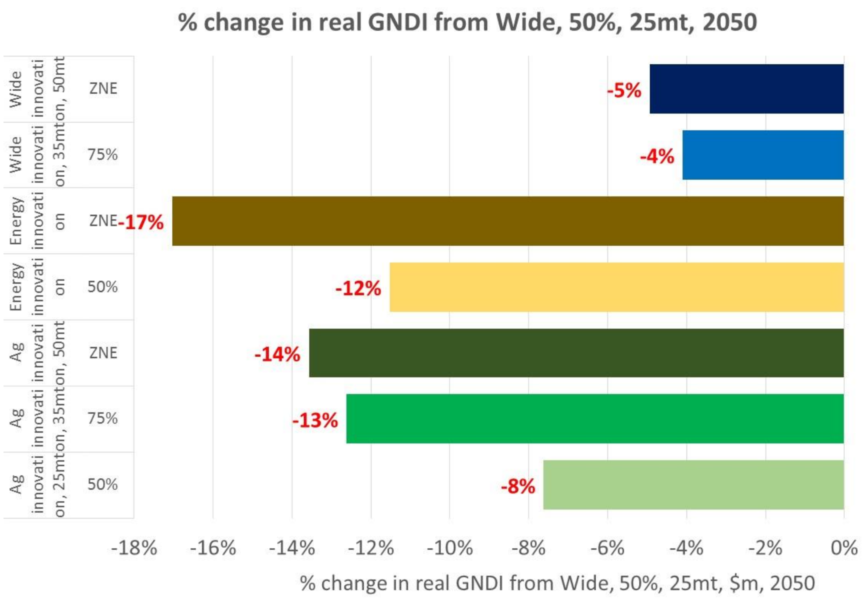
We measure the impacts on households through changes in real Gross National Disposable Income (RGDNI) per household. RGDNI is a measure of economic welfare as it adjusts changes in GDP (or income) for movements in export and import prices that affect households' purchasing power.

As Figure 15 shows, household welfare will be between 5% and 17% lower than the status quo by 2050 for the ZNE scenarios.

This is due to higher costs of goods and services that are pushed up by higher carbon prices, and a softer labour market outlook.

Figure 15 Change in household welfare

% change from status quo, 2050



Source: NZIER

We can also look at these impacts on a *per-household basis* by dividing the results by the number of households projected by Statistics New Zealand.[17]

Table 15 shows these results. Per-household welfare is around $183,000 in 2017, and is projected to be $275,000 in the status quo by 2050.

For the ZNE target scenarios, per household welfare would be between $13,600 and $46,800 lower than status quo by 2050.

[17] Statistics New Zealand's national family and household projections, 2013base: 2038 update. We use the Medium A: Assuming medium fertility, medium mortality, medium migration, and 'A' living arrangement type rates scenario. We interpolate between 5-year projections; and extrapolate to 2050 using 2033-2038 growth rates.

Table 15 Per household welfare impacts in 2050 against status quo

Real Gross National Disposable Income per household, compared to 2050 status quo of $274,800

Scenario	50%	75%	ZNE
Ag innovation	-$21,000 (-8%)	-$34,700 (-13%)	-$37,300 (-14%)
Energy innovation	-$31,700 (-12%)	Not modelled	-$46,800 (-17%)
Wide innovation	-	-$11,300 (-4%)	-$13,600 (-5%)

Source: NZIER

The welfare impacts are considerably larger towards the end of the 2017-2050 period than in the earlier years before the implied carbon price really starts to bite.

4.5. Export impacts

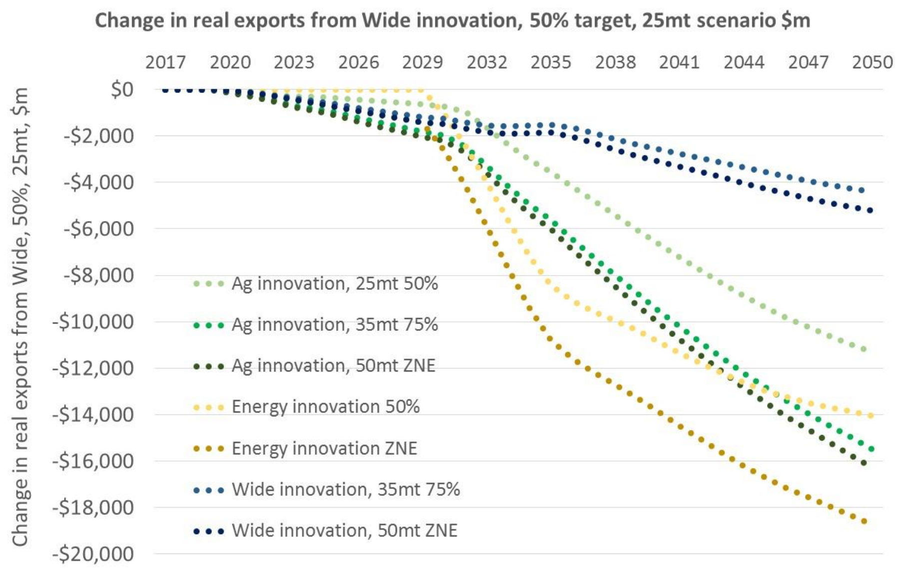
In the core scenarios, the volume of exports in 2050 falls by between $5.2 billion and $18.7 billion from the status quo of $138.2 billion for the ZNE target scenarios.

This is due to the contraction of most export industries, and especially those who are emissions-intensive such as dairy, sheep and beef, steel and aluminium.

Recall that in the core scenarios, free allocation is phased out gradually as we assume the rest of the world also takes strong action on climate change.

Figure 16 Impacts on export volumes – levels

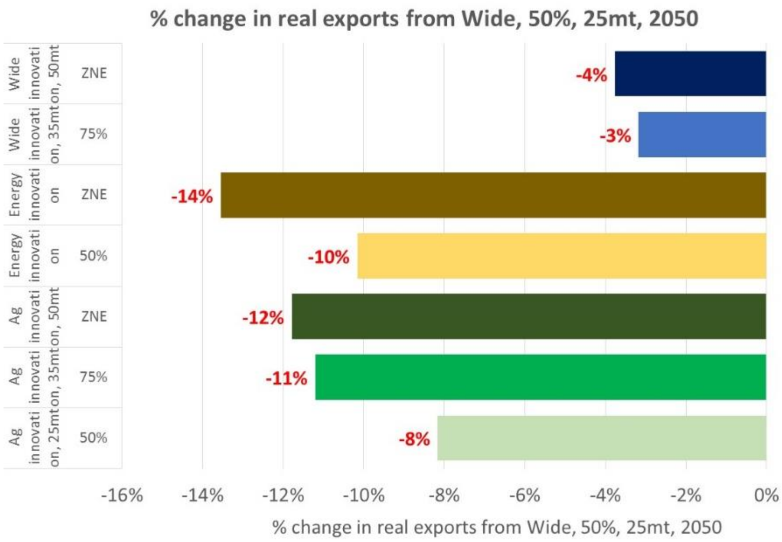
$ millions, change from status quo



Source: NZIER

Figure 17 Impacts on export volumes – %

% change from 2050 status quo of $138.2 billion



Source: NZIER

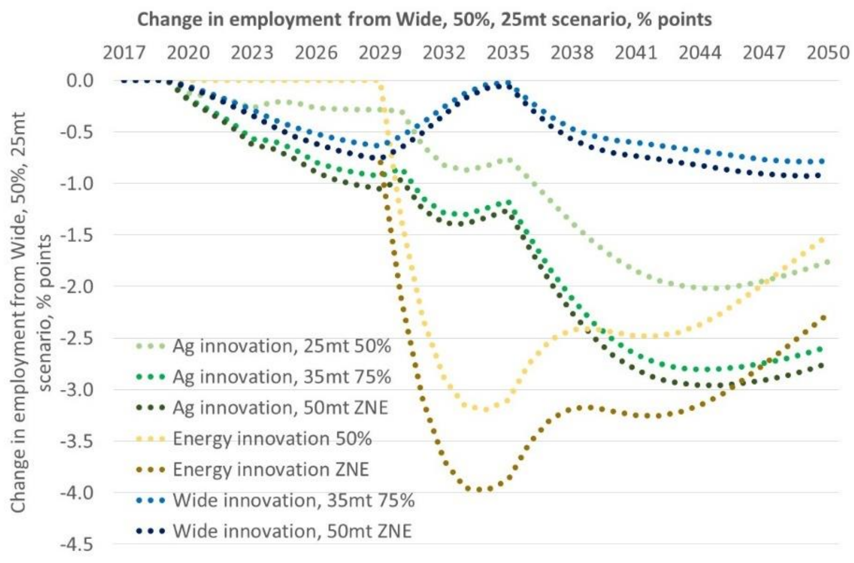
4.6. Labour market impacts

In our dynamic modelling framework, employment attempts to return to its baseline level over time, meaning most labour market impacts are felt through changes to real wages.

Employment is expected to fall by between 0.9% and 2.7% below status quo by 2050 in the ZNE scenarios (Figure 18). The lower the target, the lower the employment impact. Real wages also fall substantially in some scenarios – by a minimum of 6.7% below the status quo by 2050 for the 75% target with Wide innovation (Figure 19).

Figure 18 Impact on employment

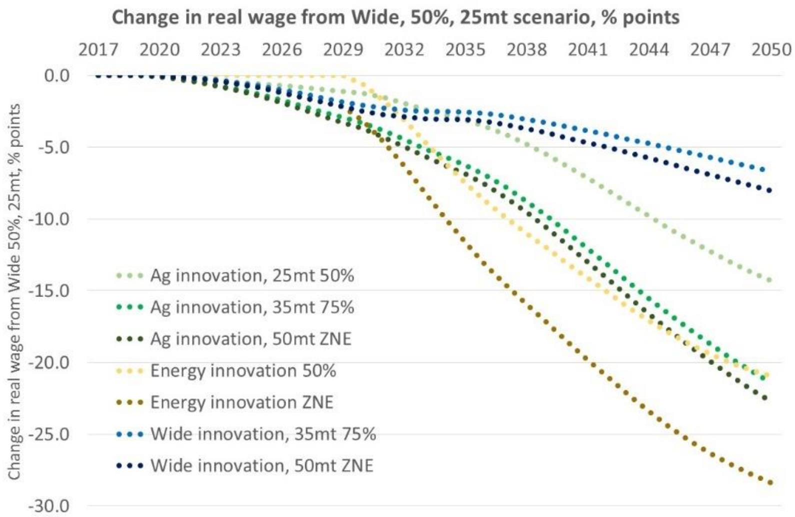
% points change from status quo



Source: NZIER

Figure 19 Impact on real wages

% points change from status quo



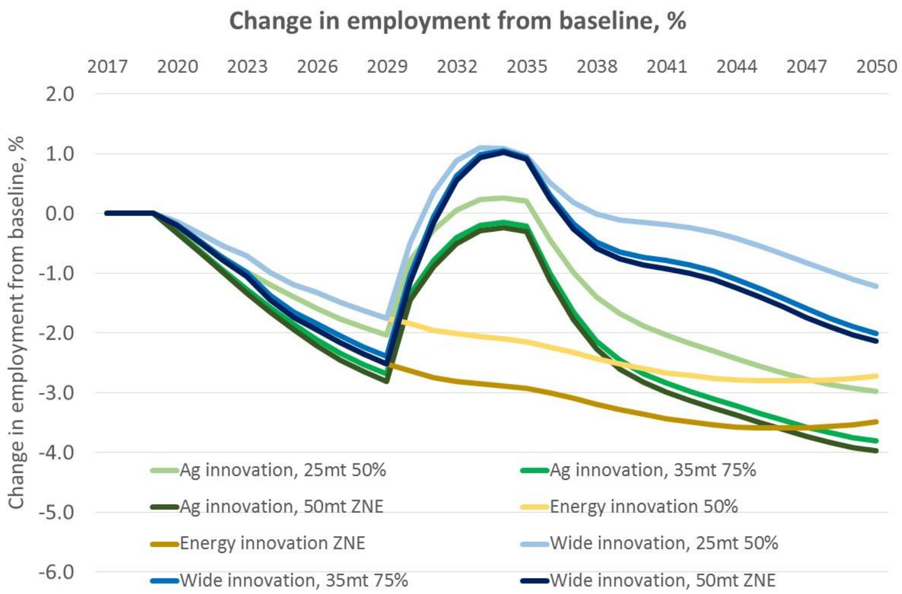
Source: NZIER

The seemingly pronounced employment impacts in the Energy innovation scenarios around 2030 are largely a result of the choice of status quo against which we compare the results in Figure 18.

In the Wide innovation, 50% target status quo scenario, employment actually lifts above baseline in 2030, due to the introduction of the methane vaccine which substantially boosts productivity in the dairy and sheep and beef industries (see Figure 20 below). Therefore, the Energy innovation scenario employment results look particularly bad when compared against the status quo.

Figure 20 Employment impacts compared against baseline

% change in employment, compared to baseline



Source: NZIER

Note that we incorporate expected labour force growth into our baseline scenario, so these reported employment declines are from a higher level than current employment:

- In our baseline, employment grows by 22.2% between 2017 and 2050.
- In the status quo, employment grows by 20.7% from 2017.
- In the Wide innovation, ZNE scenario, this growth from 2017 drops marginally to 19.6%.

Also recall that these results do not incorporate any specific government initiatives to ease the employment or wages impacts of meeting emissions targets.

4.7. Implied carbon price

The implied carbon price is best characterised as an economy-wide average price on firms' emissions. They will pay this price when it is lower than the cost of abating.

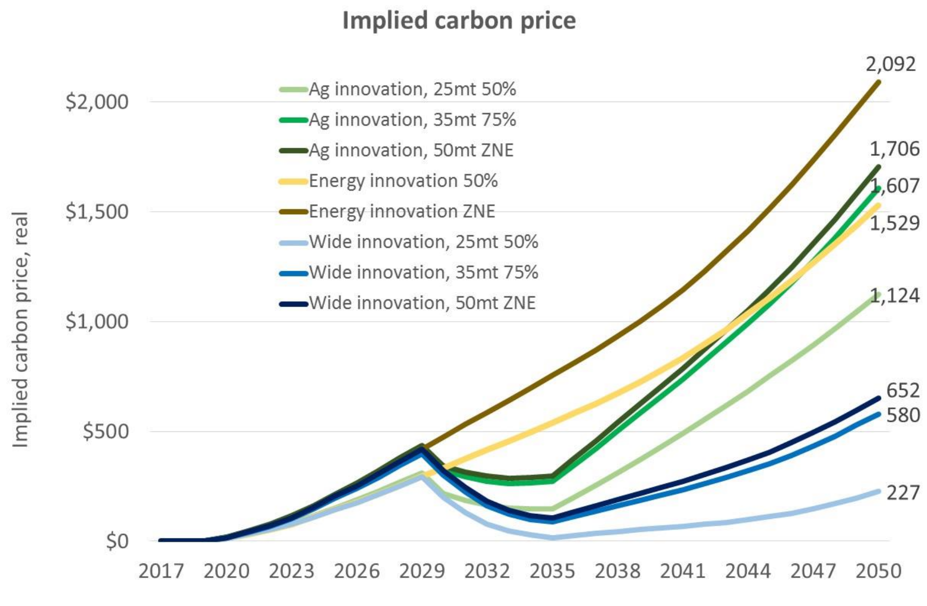
Before this point on their abatement cost curve, it makes more sense for firms to switch away from emissions-intensive inputs.

If the government seeks to reduce emissions by regulations instead of via an emissions price, the implied price each firm will face depends on what the government does to share the cost burden. This would vary across industries. But since we don't know what package of measures the government may take, we simulate an economy-wide price.

The time profile of domestic carbon prices that the CGE model solves for under each combination of scenario and target is shown in Figure 21.

Figure 21 Implied carbon price

Per tonne CO2-e



Source: NZIER

Table 18 shows average implied carbon prices across the 2020-2050 period.

Table 16 Average implied carbon prices

Per tonne CO2-e, average 2020-2050

Scenario	Ag	Ag	Ag	Energy	Energy	Wide	Wide	Wide
Target	**50%**	**75%**	**ZNE**	**50%**	**ZNE**	**50%**	**75%**	**ZNE**
Av carbon price	$386	$568	$605	$612	$845	$109	$243	$272

Source: NZIER

Point estimates for 2030 and 2050 are shown in Table 17.

The more stringent the emissions target, the higher the carbon price required to incentivise the behavioural changes necessary to move to a lower emissions economy.

Prices are higher in the Energy innovation scenarios because they do not involve any additional net sequestration relative to the baseline. This forces the rest of the economy to move higher up its aggregate marginal abatement cost curve to meet any given emissions target.

The impact of introducing the methane vaccine in 2030 is noticeable. It makes abatement in New Zealand much less costly, and is a clear example of how innovation and R&D in emissions-reducing technologies will ease the burden of adjusting to the challenges of climate change.

Table 17 Carbon price in 2030 and 2050

$ per tonne of CO2-e

Scenario	50%		75%		ZNE	
	2030	**2050**	**2030**	**2050**	**2030**	**2050**
Ag innovation	$216	$1,124	$320	$1,607	$341	$1,706
Energy innovation	$333	$1,529	Not modelled		$475	$2,092
Wide innovation	$200	$227	$302	$580	$323	$652

Source: NZIER

An alternative way of looking at the change in the carbon price required to meet the more ambitious 75% and ZNE emissions targets is to compare the prices generated in these scenarios against the prices in our status quo scenario.

These differentials are shown in Table 18, and show that for the ZNE target scenarios, the implied carbon price in 2050 will be between $425 and $1,479 per tonne higher than in the status quo scenario.

The differentials are between $123 and $275 in 2030 for the ZNE scenarios.

Table 18 Differential in carbon price from status quo

$ per tonne of CO2-e, 2030 and 2050; compared to Wide innovation, 50%, 25Mt scenario

Scenario	75%		ZNE	
	2030	2050	2030	2050
Ag innovation	+$120	+$1,380	+$142	+$1,479
Energy innovation	Not modelled		+$275	+$1,865
Wide innovation	+$102	+$353	+$123	+$425

Source: NZIER

Carbon prices at these levels stretch our models

We note that at the very high carbon prices in some scenarios, it is difficult to be confident in how firms and households will respond. The implied changes in relative prices are well beyond the range over which our model has been calibrated.

For example, if someone gets a pay increase of $5,000, their previous patterns of consumption will give a good approximation of what they will spend this additional income on. Our model would work well here.

If that person wins $20 million on Lotto, however, they are likely to buy a very different bundle of goods and services, which would be hard to predict. Our model would be less useful here.

The same logic applies to carbon prices. If they go up 5%, we have a good idea of how households and firms will respond. If they go up 200%, it's hard to predict with certainty what choices people and businesses would make.

Comparison with Vivid, Concept and Motu's results

These implied carbon prices are considerably higher than those estimated by other researchers such as Vivid, Concept and Motu [VCM] (2018, p.4), who concluded that:

> *New Zealand is likely to be able to decarbonise its economy at a cost comparable to that expected in the rest of the developed world… reach[ing] a more stringent net zero emissions constraint by 2050 with a 2050 emissions price of between NZ$150/tCO2e to NZ$250/tCO2e.*

VCM's estimates were generated by linking a highly detailed energy and industry model with a detailed national scale, spatial, partial equilibrium model of rural land use. This modelling approach generates deep insights into how changes in economic incentives drive land use change, and how emitting sectors can meet demand at least cost (VCM, 2018, p.13).

As the authors of that study note (p.14), their bottom-up linked model focuses on "accurately depicting the incentives and outcomes within their specific sectors of focus. This means that while they provide a richness of detail that can be lacking in other models, they are unable to provide estimates of aggregate whole-of-New Zealand economic cost of different pathways".

That is, it will not produce macroeconomic results such as GDP, GNDI, employment, exports, etc., which is what we have been asked to focus on in this report.

VCM’s modelling framework does not incorporate the types of constraints that a CGE model includes, such as those related to households’ budgets, government spending, balance of payments, terms of trade, labour and capital constraints.

These constraints will tend to increase price changes relative to those generated by partial equilibrium models as there is no ‘escape valve’ in CGE models.

Another difference between the modelling approaches is that in VCM, “emission price trajectories in the period to 2030 are exogenously determined” (VCM, 2018, p.22). That is, in the early part of the projection period these prices are assumed, rather than being outputs of the models.

In contrast, in our CGE approach, the emissions price is *endogenously* determined in all years – we let the model solve for the emissions price, given a specific emissions target and a wide range of other assumptions.

Our models also incorporate different sets of assumptions. For example, the VCM modelling “pathways constrain the expansion of dairy farming, with no new land converted to dairying beyond 2025” (VCM, 2018, p.53). This will likely reduce dairy farming emissions, and hence reduce the required carbon price to meet a given 2050 target, relative to our approach, as we do not apply such a constraint.

None of this is to diminish the value of alternative modelling approaches. The VCM approach has considerably more detail on land use change than our model, and a much more granular representation of energy production, for example.

All models have strengths and weaknesses, and for policy issues such as climate change, there is considerable value in having a range of models to provide different insights into the main issues in play. The main strength of our approach, for this research objective, is that it generates whole-of-economy costs.

As VCM (2018, p.44) note, “While providing an improved evidence base, this modelling will necessarily provide an incomplete picture. This can assist in decision-making, but social choice requires that a far wider range of trade-offs are considered and balanced in a manner that is clearly the domain of the government and society”.

The same can be said about our CGE modelling work. It hopefully provides some insights into the trade-offs involved, at a macroeconomic level, in moving towards 2050 emissions targets with differing levels of ambition, but it cannot provide all of the answers to what are highly complex economic and environmental questions over a 30+ year timeframe.

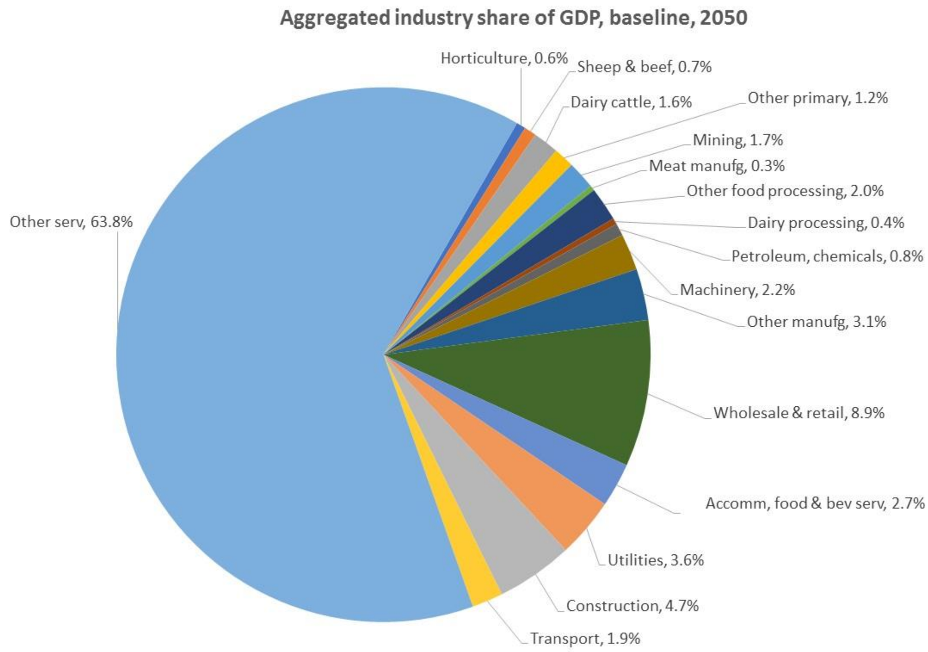
4.8. GDP impacts by broad industry

Our CGE model produces results at the 111-industry level. However, for ease of presentation, we have aggregated these industries into 15 broader industries to show the distributional impacts of the various scenarios and emissions targets.[18]

The aggregation mapping can be seen in Appendix D and the shares of the 15 industries is shown in Figure 22. These shares are useful context when looking at the percentage change in industry value added in Figure 23 to Figure 25.

Figure 22 Composition of economy by broad industry

Industry share of GDP, baseline, 2050



Source: NZIER

For the sake of brevity and avoiding number soup, we present only the results from the ZNE target scenarios, relative to the status quo (see Figure 23 overleaf).

We also show the ZNE target scenarios relative to the baseline to show the full adjustment required between now and 2050, rather than solely the marginal effects from the status quo scenario (see Figure 24).

The industry results for the 50% and 75% scenarios are available on request.

There are two key drivers of these results:

1. **The income effect** – as the economy grows less rapidly under scenarios with more ambitious emissions targets, there is lower demand for all goods and services.

18 We need to acknowledge the risk of aggregation bias in taking this approach: within these broad aggregates, some industries will be more affected by emissions targets; others less affected. See section 4.9 below for the more detailed industry results for the Wide innovation, ZNE target scenario.

2. **The substitution effect** – industries which are relatively low emissions-intensive face a lesser cost imposition from high carbon prices. This allows them to expand, or at least contract less than more emissions-intensive industries.

As would be expected, given the magnitude of carbon price increases required to meet a ZNE target, the industries most affected are those that are emissions-intensive, such as the petroleum and chemicals sector.

These adjustments are less severe under the Wide innovation scenario, though still indicate that the economy will undergo significant structural change in order to meet ambitious emissions targets by 2050. Note that we have not modelled any additional government policies that could be taken to support the most-effected industries through the transition to a lower-emissions economy.

In the Ag innovation scenario, dairy and meat processing actually expand *relative to the status quo*. This counter-intuitive result is due to the boost to on-farm productivity resulting from the methane vaccine.

Note, however, that when *compared to the baseline* (Figure 24), dairy and meat processing will face significant adjustment costs. This takes into account the costs of moving from the current state to the Wide innovation, 50% target status quo scenario.

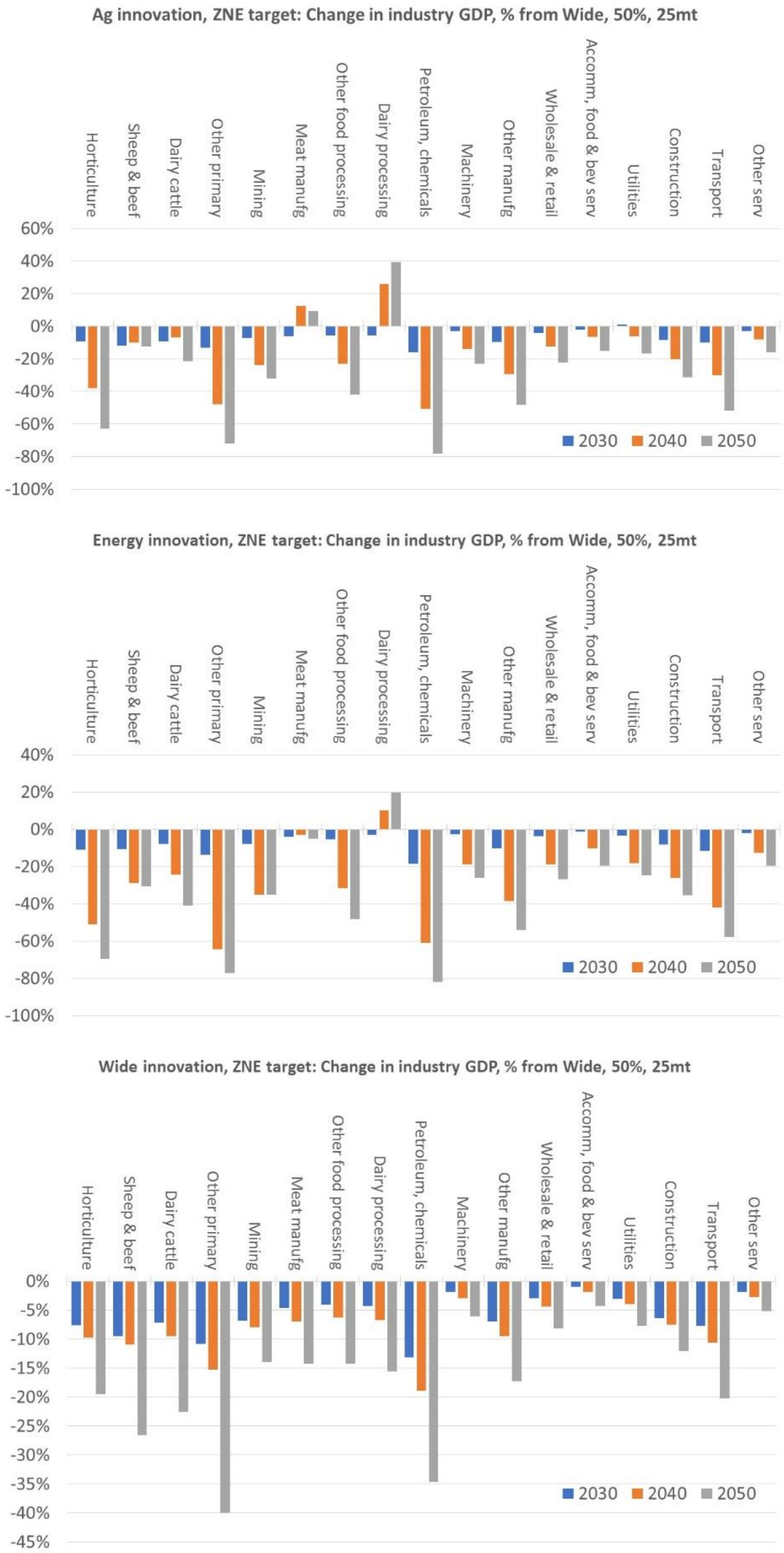
The services sectors and some less emissions-intensive machinery and manufacturing are far less affected.

Horticulture benefits (in relative terms at least) from our assumed shift in global consumer preferences away from dairy and meat towards lower-emissions foodstuffs.

See section 4.9.1 below for a discussion on the potential impacts on the forestry and wood processing industries.

Figure 23 Industry GDP impacts for Ag, Energy and Wide innovation scenarios, ZNE target compared to status quo

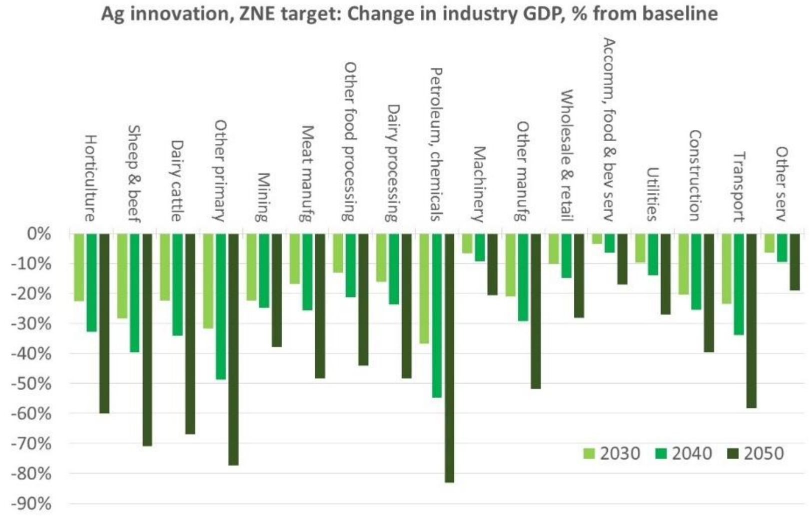
% change in industry value added from status quo in 2030, 2040, 2050

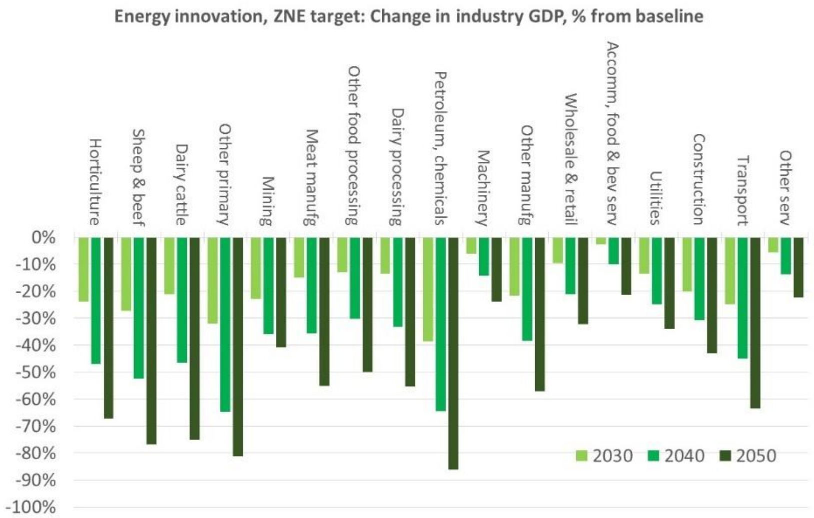


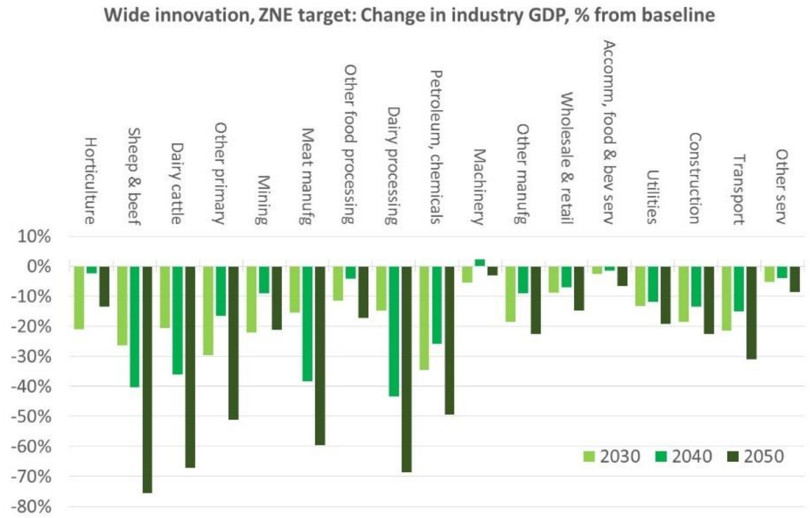
Source: NZIER

Figure 24 Industry GDP impacts for Ag, Energy and Wide innovation scenarios, ZNE target compared to baseline

% change in industry value added from baseline in 2030, 2040, 2050







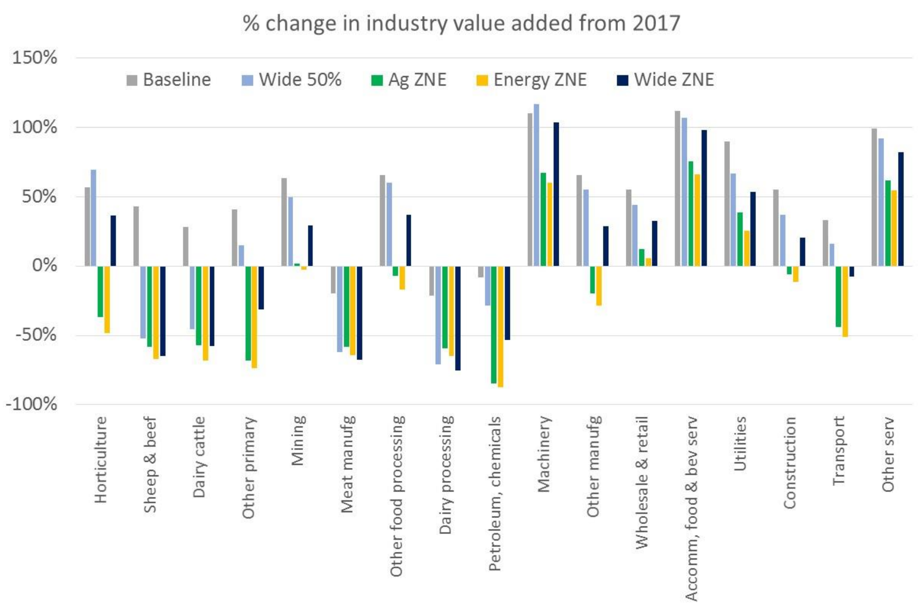
Source: NZIER

It is also interesting to compare the size of industries in 2050 under the emissions target scenarios with their current size. As Figure 25 shows, many emissions-intensive industries will be smaller than they currently are by 2050, including sheep and beef and dairy farming and their downstream processing industries, and petroleum and chemicals. Additional government support to ease their transition is likely to be warranted.

The relatively low-emissions services sectors show strong growth from current levels, aside from transport, which becomes much smaller as energy efficiency improves. Recall that the 'Other services' industry accounts for over 60% of the economy (Figure 22), so its expansion plays a key role in supporting economic growth between 2017-2050 in all scenarios.

Figure 25 Change in industry value added from 2017

% change in industry value added from 2017



Source: NZIER

Our analysis of the industry impacts of meeting more ambitious 2050 emissions targets are consistent with the findings of the New Zealand Productivity Commission (2018, p. 10), which concluded that:

> *An effective transition to a low-emissions economy will mean that New Zealand will look very different in 2050. During the transition, action to mitigate GHG emissions will require real and significant changes. Those changes will have disruptive impacts on some businesses and households.*

4.9. Industry impacts at a more detailed level

As noted above, we also have the industry impacts at the 111-industry level.

To show the full extent of the potential structural change between now and 2050, the charts below in Figure 26 and Figure 27 show the detailed industry impacts, *relative to the baseline* of the Wide innovation, ZNE scenario, using change in 2050 levels instead of percentage change.

A more detailed industry disaggregation of the results shows that renewable energy generation industries (geothermal, hydro and wind) expand when emissions targets are imposed and carbon prices rise.

There are also small gains for lower emissions-intensive manufacturing industries such as electrical equipment manufacturing and clothing manufacturing; and services industries such as accommodation, movies and rental services.

4.9.1. The forestry and wood processing industries will gain

The results in Figure 26 and Figure 27 suggest that the forestry industry and wood processing industries will contract in 2050 relative to the baseline.

That makes little sense, given the expansion in afforestation we assume in the Wide innovation scenario (50Mt in the ZNE target scenario).

The modelled contraction is due to the way that we deal with net sequestration. As discussed in the caveats in section 1.2, net sequestration is not determined inside the modelling framework – it does not respond to the carbon price.

Rather, we impose net sequestration exogenously on the emissions profile, reducing the amount of abatement that the rest of the economy needs to do to meet any given target.

When we exogenously impose net sequestration on the economy, we do not require the forestry sector to expand by an equivalent amount.

We will look to address this shortcoming of our approach in Stage 2 of this research, potentially by introducing an exogenous export demand shock for logs and processed wood products.

In the interim, we have performed an indicative analysis of the likely growth of the forestry and downstream processing industries by 2050 from an additional 50Mt of net sequestration.

In the Wide innovation, ZNE scenario, we assume an additional 50Mt of net sequestration by 2050. This would represent a 140% increase in the forested harvest area relative to the current area.[19]

Based on this expansion, an indicative out-of-model calculation suggests:

- The forestry industry would grow from $1.3 billion of value-added in 2017 to $3.1 billion in 2050 in the Wide innovation, ZNE scenario.

[19] This estimated increase in harvested area was kindly inferred by Dr Adolf Stroombergen, based on his work for the Biological Emissions Reference Group, in Motu (forthcoming).

- The wood processing industry would grow from $1.3 billion in 2017 to $3.2 billion in 2050.
- Total log and processed wood exports would increase from $3.8 billion in 2017 to $9.1 billion in 2050.

These estimates provide a better sense of the likely impacts on the forestry and wood processing industries of introducing a ZNE target than those produced in our modelling results.

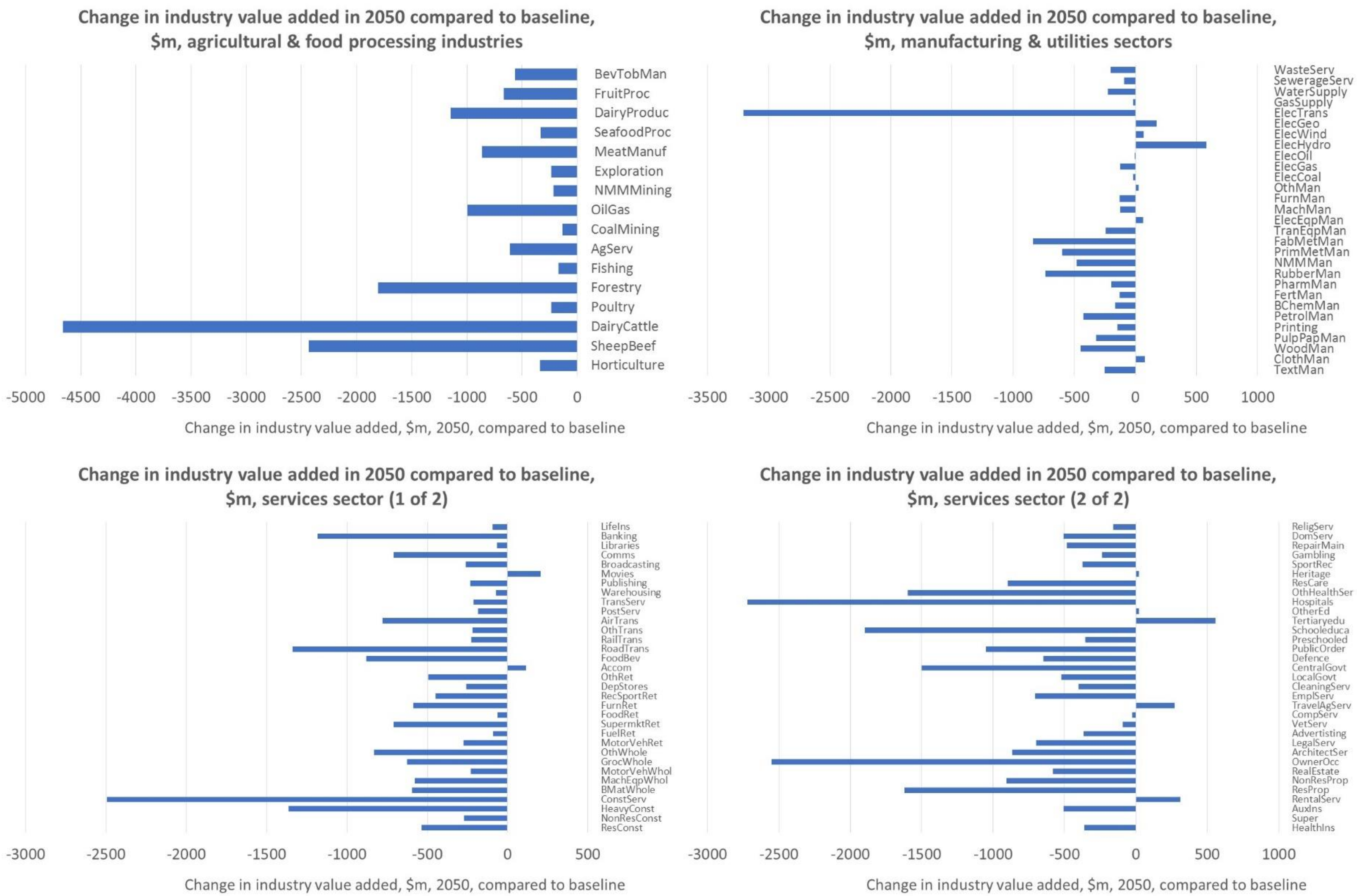
4.9.2. Workers affected by major structural change will need additional support

These significant changes in the structure of the New Zealand economy may require further policy attention, especially if workers are dislocated from emissions-intensive industries.

While our model allows labour to move between industries as they grow or contract, albeit with a lag, in practice there are challenges in doing so due to a lack of transferable skills between industries, geographical 'stickiness' of families, etc.

Figure 26 Detailed industry results for Wide innovation, ZNE target scenario - levels

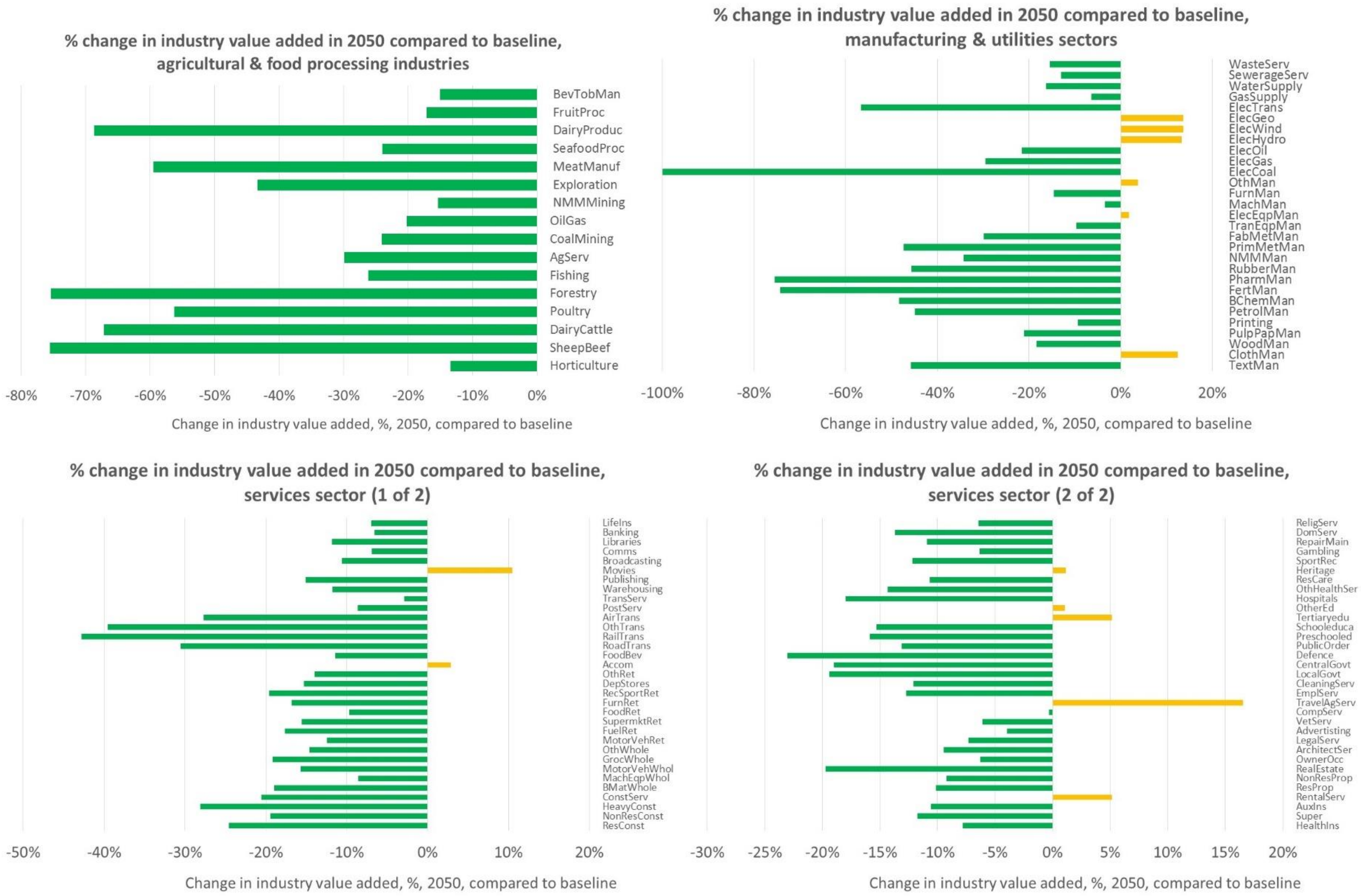
$ change in industry value added from baseline in 2050



Source: NZIER

Figure 27 Detailed industry results for Wide innovation, ZNE target scenario - % change

% change in industry value added from baseline in 2050



Source: NZIER

4.10. Distributional impacts on households

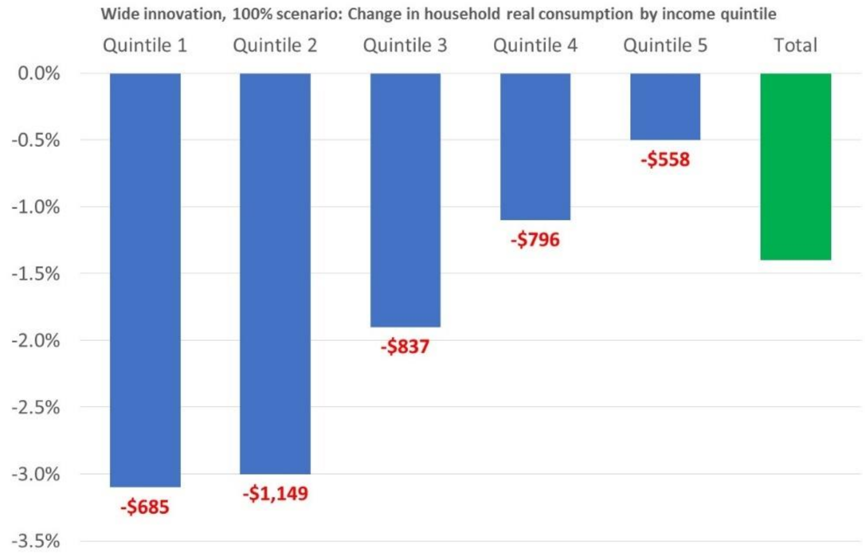
At this stage our MNZG CGE model only has a single representative household agent. We have not yet introduced households of different income levels to allow the analysis of policy changes on different types of households.

However, modelling carried out by our research partner, Infometrics, using a different CGE model, indicates that the impacts on households varies considerably by income level.

Figure 28 below shows those in the lowest income quintiles (1, 2) are most severely affected – over twice as much as the average income household in relative terms. The absolute changes are shown as the red labels in the chart.[20]

Figure 28 Impacts on household consumption: wide innovation, ZNE target

% change in 2050 real private consumption relative to baseline; by income quintile: Q1 = lowest income. Red labels show absolute decrease in per-household consumption.



Source: Infometrics ESSAM model

While these household impacts may present challenges during the transition to a lower-emissions economy, the New Zealand Productivity Commission (2018, p.9) has recently noted that:

> *The adverse impact of such [price] increases on the real incomes of vulnerable households can be offset through the tax and welfare system.*
>
> *Existing policies, such as tax credits and benefits, should be adequate to compensate lower-income households for these increased costs, provided both are regularly adjusted in line with inflation.*

[20] Because of different model structures and specifications, the overall consumption decrease result estimated by Infometrics differs from our RGNDI per household impacts. What is more important here, however, is the *relative* impacts between income groupings, rather than the precise level.

4.11. Sensitivity analysis

4.11.1. Wide innovation, trade in permits scenario

Sensitivity analysis scenario design

In previous modelling exercises of New Zealand's climate change policy (see NZIER and Infometrics 2009, 2011), New Zealand firms had access to international emissions permits. When the cost of abating domestically was higher than the international permit price, firms bought permits to minimise costs.

In the core scenarios in this report, we assume no access to permits. We relax this assumption in this sensitivity analysis, using the Wide innovation, ZNE target as the comparator core scenario. Firms are able to buy international permits when their cost is lower than the domestic cost of abatement.

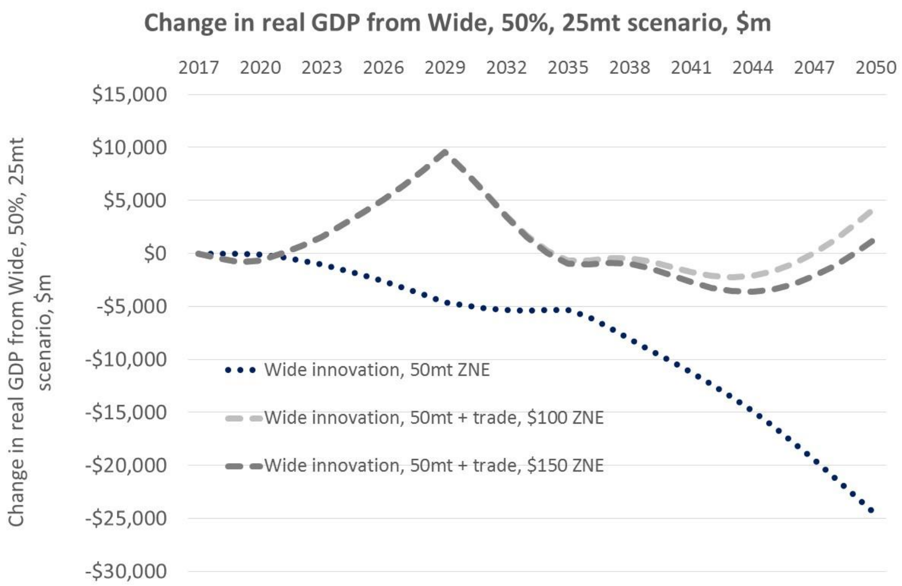
We assume, based on guidance from officials, two potential price paths for international permits:

- $20 today, rising linearly to $50 in 2030, then linearly to $100 by 2050.
- $20 today, rising linearly to $50 in 2030, then linearly to $150 by 2050.

The GDP impacts of allowing trading are shown in Figure 29. The economic costs of meeting a ZNE target fall sharply with permits trading. This is because firms choose to buy emissions permits from overseas rather than facing the high domestic abatement costs implied by imposing a stringent emissions target.

Figure 29 Sensitivity analysis: allowing international purchases of emissions permits

Change in $ millions from status quo; Wide innovation, ZNE target



Source: NZIER

Other results are summarised in Table 19.

The economic costs are marginally higher when the international price is assumed to rise to $150 instead of $100, but both sensitivity analysis scenarios show significantly lower imposts on the economy than in the core scenario. Firms are able to avoid the high domestic abatement costs that occur in the core scenario with no trade allowed.

Table 19 Permits trading sensitivity analysis – summary of economic impacts

Wide innovation scenario, ZNE target. Change from status quo, 2050; SA = sensitivity analysis scenario.

Target & net sequestration	Real GDP	Average GDP growth	Real GNDI per h/h	Employment	Real wage	Average carbon price
	% change, 2050	%, 2017-2050	$ change, 2050	% change, 2050	% change, 2050	2020-2050
Core (ZNE, 50Mt, no trade)	-4.9%	1.90%	-$13,600	-0.9%	-8.0%	$272
SA (ZNE%, 50Mt, trade, price path to $100)	+0.9%	2.08%	+$2,400	+0.9%	+0.7%	$60
SA (ZNE%, 50Mt, trade, price path to $150)	+0.3%	2.06%	+$800	+0.7%	-0.2%	$73

Source: NZIER

This sensitivity analysis demonstrates the importance of policy decisions related to access to international permits.

While abating all emissions domestically to meet a given 2050 emissions target is more consistent with a drive to a lower-emissions economy, allowing access to international permits allows New Zealand Inc to remove the same volume of emissions from the global atmosphere at a far lower economic cost.

4.11.2. Wide innovation with weak rest of world action on climate change scenario

Sensitivity analysis scenario design

In all the core scenarios, we assume – rightly or wrongly – that the rest of world broadly matches New Zealand's ambitions in terms of policy actions to address climate change.

Since ours is a single-country model, rather than a global one with multiple countries, we have to proxy global action through its expected impact on New Zealand's export competitiveness. If all our competitors take a similarly strong stance of pricing emissions, then New Zealand exporters should not experience any significant loss of price competitiveness in global markets: New Zealand exporters and producers from other economies will face a similar cost impost.

To model this situation in our single-country framework, we choose to hold the terms of trade constant. We also reduce the free allocation of emissions permits to emissions-intensive, trade-exposed industries, since this protection will no longer be required if others also price their emissions.

Clearly, assuming the rest of world matches New Zealand's policy actions towards a lower-emissions economy is heroic.

Therefore, we also explore a scenario where the rest of the world takes only weak action to address climate change. This is best thought of as the rest of the world continuing to do what it is currently doing on emissions pricing, rather than what it has announced it will do.

Under this scenario, New Zealand exporters would suffer a decline in competitiveness as they face a cost that their competitors do not. To compensate them for this, we assume free allocation is extended out to 2050 at existing levels.

All other scenario design aspects are the same as for the Wide innovation, ZNE target scenario.

Again, this is not our prediction of what will happen. It is a "what if?" scenario based on some assumptions.

In a single country model, we can only make a binary weak/strong choice, because we cannot differentiate between the actions of the US, China, India, the EU, Australia, etc. In Stage 2 of this research, we hope to use a global CGE model to explore more nuanced representations of what other countries will do and how that will affect New Zealand's economic and environmental prospects.

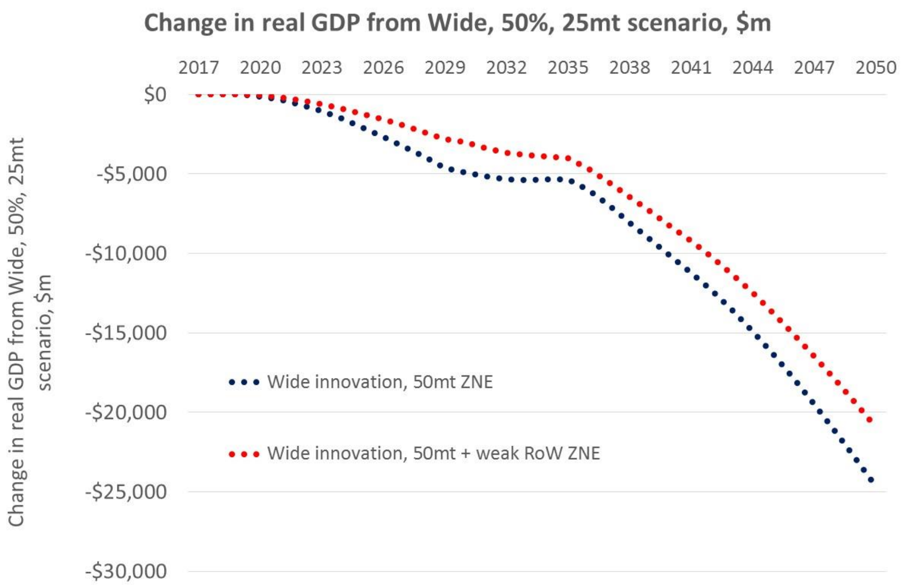
Results

The key macroeconomic impacts in this scenario are similar to that of the Wide innovation scenario with the same ZNE target (Figure 30 and Table 20).

Aside from the implied carbon price, a weak rest of the world response that is mitigated by the continuation of free allocation very slightly reduces the economic costs of meeting an emissions target. This highlights the importance of policy settings around free allocation when the actions of the rest of the world are uncertain.

Figure 30 Effects of weak global action on GDP impacts: Wide innovation scenario, ZNE target

$ millions change from status quo



Source: NZIER

Table 20 Weak global action – summary of economic impacts

Change from status quo, 2050; ZNE target; SA = sensitivity analysis scenario

RoW action	Real GDP	Average GDP growth	Real GNDI per h/h	Employment	Real wage	Average carbon price
	% change, 2050	**% 2017-2050**	**$ change, 2050**	**% change, 2050**	**% change, 2050**	**2020-2050**
Core (strong)	-4.9%	1.90%	-$13,600	-0.9%	-8.0%	$272
SA (weak)	-4.1%	1.93%	-$11,400	-0.8%	-7.3%	$283

Source: NZIER

4.11.3. Wide innovation, alternative net sequestration

Sensitivity analysis scenario design

As explained in section A.3.3, in our model, forestry planting and harvesting is not linked to the carbon price directly. We have to impose net sequestration on our model rather than letting the model determine it. This is an important area for future model development.

We take our net sequestration estimates from Vivid, Concept and Motu (2018). Net sequestration in 2050 increases from 25Mt in the 50% target scenarios to 35Mt in the 75% target scenarios and 50Mt in the ZNE scenarios, to reflect the expected rough magnitude of the response of forest owners to the higher carbon prices that more stringent emissions targets would deliver.

We recognise that this is a simplistic approach. However, given time constraints, endogenising forestry's response to the carbon price was not feasible.

However, when carbon prices are in the hundreds of dollars, as our core scenario m model results indicate, the likely forestry response will be even larger than we have imposed on the model in our core scenarios, provided there is suitable land available.

To demonstrate the effects of forestry assumptions on the macroeconomic results, we consider the Wide innovation scenario for the 50%, 75% and ZNE targets with net sequestration constant at 40Mt. We compare the results against those from our core scenarios, where net sequestration is 25Mt, 35Mt and 50Mt respectively for the three targets.

Note that for the ZNE target, this sensitivity analysis incorporates a lower rate of afforestation than in the core scenario. This could be thought of as reflecting potential environmental or societal challenges associated with planting/not harvesting the sheer volume of trees required to abate the core scenario's 50Mt of CO2-e.

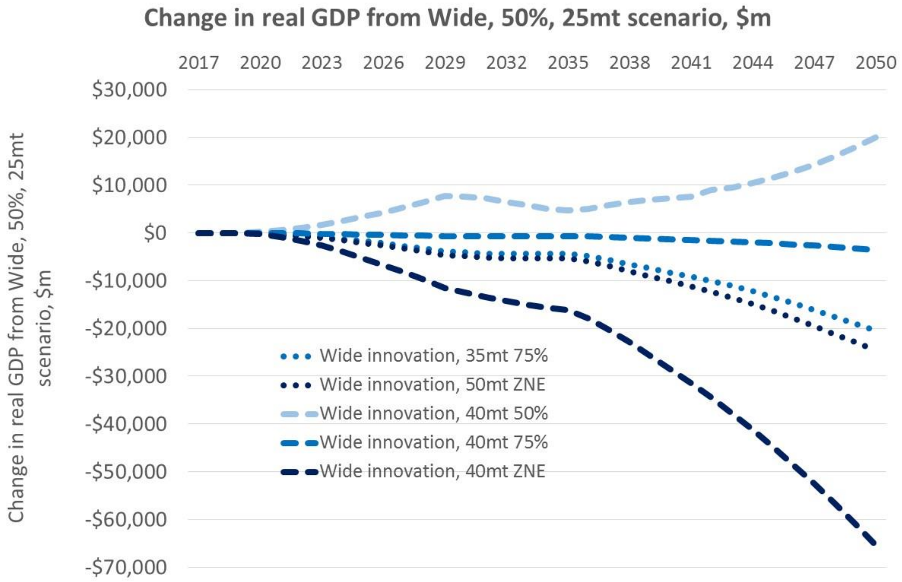
Results

As would be expected, for the 50% and 75% targets, a higher assumed rate of net sequestration reduces economic costs considerably (Figure 31 and Table 21):

- For the 50% target, using 40Mt of net sequestration instead of 25Mt shifts average annual economic growth from 2017 to 2050 from 2.06% to 2.18%.
- For the ZNE target, assuming 40Mt in this sensitivity analysis instead of 50Mt in the core scenario pushes up economic costs significantly. The change in GDP below status quo in 2050 worsens from -4.9% in the core scenario to -12.9% in the sensitivity analysis.
- Average annual economic growth between 2017 and 2050 drops from 1.90% to 1.63% for the ZNE scenarios. This could be thought of as reflecting potential environmental or societal challenges associated with planting and not harvesting the volume of trees required to abate 50Mt of CO2-e.
- The average implied carbon price from 2020 to 2050 falls as net sequestration increases. In the 75% scenarios, moving from 35Mt to 40Mt reduces the average carbon price from $243 to $131.

Figure 31 The effect of alternative net sequestration assumptions on economic impacts

All results are for the Wide innovation scenario; $ millions change in real GDP from status quo



Source: NZIER

Table 21 Alternative net sequestration sensitivity analysis – summary of economic impacts

Wide innovation scenario. Change from status quo, 2050; SA = sensitivity analysis scenario.

Target & net sequestration	Real GDP	Av GDP growth	Real GNDI per h/h	Employment	Real wage	Average carbon price
	% change, 2050	%, 2017-2050	$ change, 2050	% change, 2050	% change, 2050	2020-2050
SA (50%, 40Mt)[21]	+3.9%	2.2%	+$11,000	+1.0%	+6.1%	-
Core (75%, 35Mt)	-4.0%	1.9%	-$11,300	-0.8%	-6.7%	$243
SA (75%, 40Mt)	-0.7%	2.0%	-$1,933	-0.2%	-1.2%	$131
Core (ZNE, 50Mt)	-4.9%	1.9%	-$13,600	-0.9%	-8.0%	$272
SA (ZNE, 40Mt)	-12.9%	1.6%	-$36,000	-2.3%	-20.1%	$569

Source: NZIER

[21] Note that in the sensitivity analysis for a 50% target, there is so much net sequestration that the rest of the economy is not forced to abate anything more to reach the target. Hence there is no carbon price required.

5. Conclusions and next steps

What we did

We use a single-country, dynamic CGE model to examine the macroeconomic impacts of adopting different 2050 emissions targets under scenarios that incorporate varying degrees of:

- Afforestation
- EV uptake
- Economy-wide energy efficiency gains
- Agricultural emissions-reduction technology
- Global preferences for emissions-intensive food
- Shift to renewable energy
- Access to international permits
- Rest of world action on climate change.

Exploring economic and environmental impacts over such a long projection period inevitably requires using many assumptions, all of which can be challenged. We have sought to be as transparent as possible with our assumptions, and have used a range of scenarios and sensitivity analyses to examine the effects of changing some of the key assumptions.

Nevertheless, our results should only be seen as indicative of the magnitude and direction of the economic impacts of meeting different emissions targets, not as precise forecasts.

What we found: meeting ambitious targets comes at significant cost to the economy

We find that even with a set of optimistic assumptions around afforestation, EV uptake, agricultural innovation and global preference changes for our dairy and sheep and beef exports, the GDP impacts of meeting ZNE targets are significant at between 4.9% ($24.6 billion) and 16.8% ($85.2 billion) lower than the status quo by 2050.

The New Zealand economy will continue to grow under all scenarios modelled, but average real GDP growth will fall from 2.2% in the baseline to between 1.5% and 2.1% across our eight core scenario/target combinations.

Per-household welfare, as measured by real Gross National Disposable Income, will be between $13,600 and $46,800 lower than status quo by 2050 for the ZNE scenarios. This is due to higher costs of goods and services that are pushed up by higher carbon prices, and a softer labour market outlook that reduces employment and real wages.

The costs of meeting 2050 emissions targets fall disproportionately on lower income households. Those in the lowest income quintiles are most severely affected – over twice as much as the average household in relative terms. This may have implications for the tax and benefit system.

Industries that are emissions-intensive, such as dairy and sheep and beef farming and processing, petroleum and chemicals manufacturing will face significant costs when ambitious emissions targets are imposed.

Note that we do not consider here the avoided costs of the physical harm of climate change or the potential co-benefits of moving towards a lower-emissions economy, such as improved water quality or health benefits. These effects would reduce the overall net social costs of meeting emissions targets.

We do not explore the potential for changes in government policy to support the most affected industries or households. Such policies could reduce the burden of meeting stringent targets on some parts of society, but would result in other parts of society needing to bear a relatively higher burden than otherwise.

How can the economic costs of meeting emissions targets be reduced?

Through sensitivity analysis, we show that the economic costs of meeting any given emissions target can be reduced significantly by greater afforestation.

As net sequestration rises, the amount of abatement that the rest of the economy must deliver falls, which mitigates some of the cost. This underscores the importance of better understanding how the forestry sector will respond to higher carbon prices.

In our core scenarios, we assume that all abatement to meet emissions targets has to occur domestically. If we introduce access to international emissions permits, economy-wide costs fall sharply. This is because firms choose to purchase permits instead of facing the (higher) domestic cost of abatement.

We also show that the export competitiveness risks associated with the rest of the world taking weak action on climate change while New Zealand introduces ambitious emissions targets can be largely mitigated by extending free allocation to emissions-intensive, trade-exposed firms at existing levels.

What next?

In the next phase of this research, we will seek to consider:

- Alternative scenarios that consider the actions of specific countries or groups of countries to address climate change concerns, and how this affects the economic impacts on New Zealand of meeting 2050 emissions targets.
- The economic costs of New Zealand inaction on climate change, such as changes to crop yields or the costs of infrastructure damage from more frequent or more intense storms.
- The regional economic impacts of meeting emissions targets.
- Different combinations of the various assumptions employed in this report, or alternative innovation specifications.

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Appendix A Baseline development

A.1 What is the baseline?

The first step in any CGE modelling exercise is developing a baseline scenario against which all alternative scenarios can be compared. For this project, this required:

- Projecting the New Zealand economy out to 2050
- Estimating the emissions profile associated with this economic growth.

In the baseline, we assume that current climate change policy settings continue, but that no new policies are introduced. We also incorporate trends in energy efficiency by industry into the baseline.

It is important to note that the baseline is not our forecast of what *will* happen over the next three decades. Rather, it paints a picture of what *would* happen if there are no new climate changes measures implemented by the New Zealand government.

Clearly this is unrealistic, but the baseline gives us a business as usual scenario of economic activity and emissions, against which counterfactual 'what if' scenarios can be compared.

The difference between the baseline and counterfactual scenarios can be seen as the economic impact and emissions impact of government policies or technological developments. This allows us to explore the key trade-offs associated with climate change policy changes: how much would New Zealand's emissions decrease by, and what economic costs and benefits would result?[22]

A.2 Macroeconomic projections

Our CGE database is based on Statistics New Zealand's 2013 input-output tables, released in 2016. These tables show how the 106 industries in the New Zealand economy buy from and sell to each other, buy imported inputs to production, sell to New Zealand households, the New Zealand government and overseas consumers (via exports).

We then updated the 2013 input-output table to 2016 to reflect any changes in the structure of the New Zealand economy since 2013. We do this primarily using employment data by industry. We also added more detail on electricity generation, which increased the number of industries to 111.

The next step is projecting the 2016 economy out to 2050. In our economic baseline projections, we used Treasury's Long Term Fiscal Model macroeconomic projections (mainly real GDP and labour supply) to 2050.

[22] In general, climate change policies involve imposing costs over and above the baseline on the New Zealand economy in an effort to reduce economic activity in emissions-intensive industries. While there may be offsetting additional economic activity in less emissions-intensive industries as resources (land, labour, capital, energy) are reallocated in response to the policy change, this usually has an overall negative effect on economywide economic activity. The picture is different with scenarios incorporating technological change, as these can both increase economic activity and reduce emissions.

Table 22 Baseline economic growth projections

Real GDP

Period	Average GDP growth
2017-2030	2.27%
2030-2050	2.04%

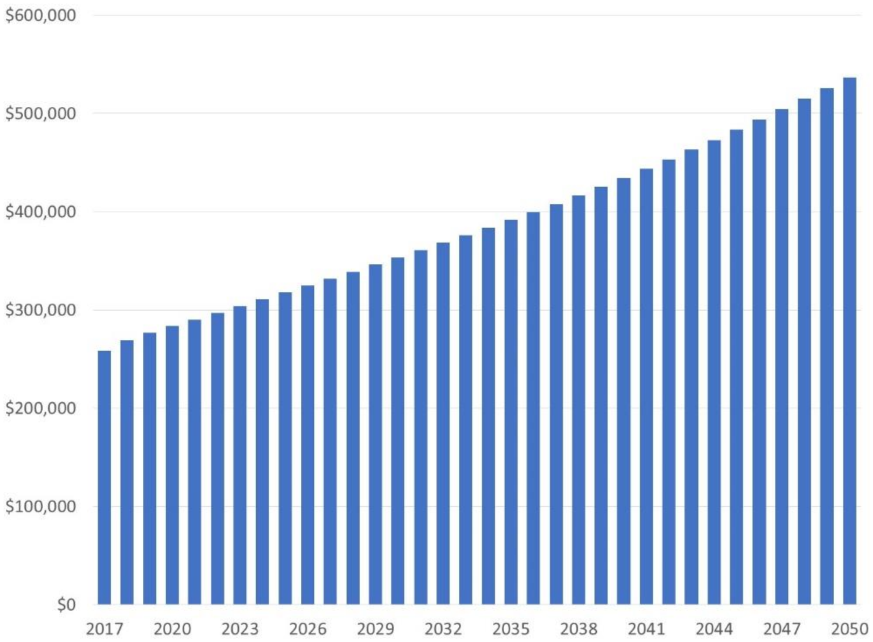
Source: Treasury LTFM, November 2016 update

We initially project the economy at the macroeconomic level, and then let the model determine how this economic activity will be apportioned across the 111 industries in our model. Where we had industry-specific economic projections from government agencies (as per section 2.2), we then calibrated the baseline to reflect these 'official' estimates.[23]

Figure 32 shows our baseline projection for economy-wide GDP out to 2050. The economy more than doubles in size (108% expansion) between 2017 and 2050.

Figure 32 Baseline macroeconomic projection

Real GDP, $ millions



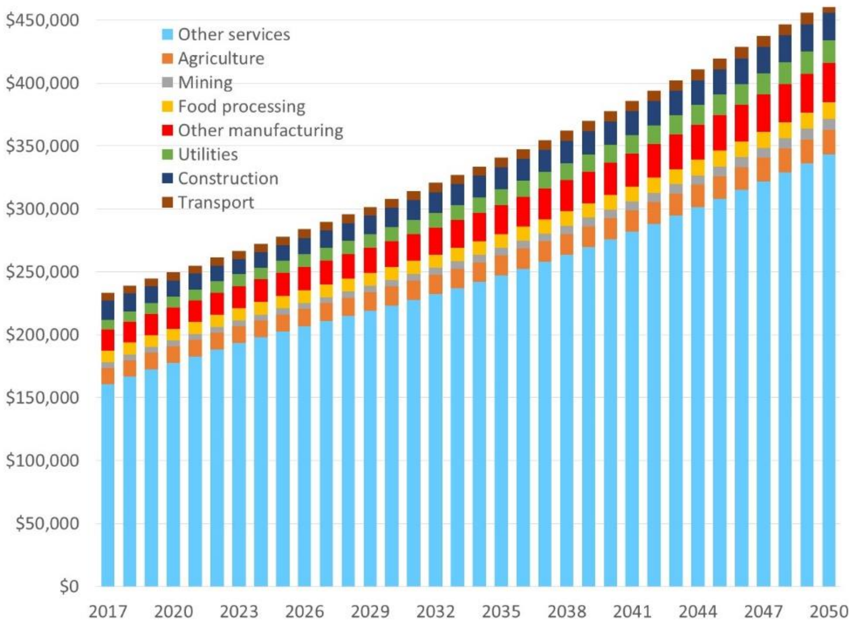
Source: NZIER, Treasury LTFM

The composition of the economy changes over time to reflect historical structural trends, such as the growth of the services sector as incomes rise.

[23] There will be some differences in levels between our industry projections and those provided by agencies simply due to our different methodologies, but the trends by industry are largely consistent. Recall that the precise level of the baseline economic activity by industry is not critical for this analysis, provided it is reasonable.

Figure 33 Economic activity by broad sector in baseline projection

Real GDP (factor cost)[24], $ millions



Source: NZIER

Trying to determine what the New Zealand economy will look like over 30 years into the future is fraught with uncertainty. It is impossible to predict with any degree of confidence what types of global and national policy and disruptive 'step change' technological changes will happen, so we do not try beyond including existing policies and energy efficiency trends.

Potential policy or technological changes are therefore captured in the scenario analysis.

A.3 Emissions projections

A.3.1 Overview of approach

There are no publicly available economy-wide government projections of New Zealand's emissions out to 2050. Previous government projections for the economy as a whole have been to 2030 only.

Officials therefore asked us to prepare our own baseline emissions projections to ensure that these emissions were internally consistent with our economic projections.

As with the economic projections, the first step is to determine the emissions make-up of the economy and its 111 industries in our base year, 2016. To do so, we use data from New Zealand's 7th National Communication to the UNFCCC, along with data on fuel use by broad industry from MBIE. We also align emissions by broad industry with

24 The sum of industry real GDP at factor cost differs slightly to Treasury's estimates of economywide real GDP due to the former excluding taxes.

those from Statistics New Zealand’s Environmental-economic accounts (Statistics New Zealand, 2018).

Note that we sought to align the assumptions from these sources with those in our model, rather than aiming to recreate the emissions profile suggested by previous modelling.

This provides us with a picture of each industry’s CO2-e emissions per unit of GDP generated, and New Zealand’s overall emissions in 2016.

We then project the economy and its 111 industries out to 2050 (described above), and let emissions grow accordingly, without considering the impacts of any new climate change policies. Historical trends in emissions intensity by sector are projected forwards where we do not have specific information from agencies.

Because our economic baseline assumes total factor productivity improvements in line with historical trends, industries are able to use proportionately less of all inputs, including energy, to produce each unit of GDP. This is a key reason why emissions grow more slowly than GDP in the baseline projections.

We then refine the emissions baseline by paying particular attention to key emitting industries for which emissions profiles have been constructed by government agencies. These are shown in Table 23 and are explored further in Appendix C.[25]

Table 23 Sector-specific baseline emissions assumptions sources

Sector	Source	Comment
Dairy farming	MPI	Emissions from dairy cattle based on projected animal numbers and projections of animal productivity (i.e. milk yield)
Sheep farming	MPI	Emissions from sheep based on projected animal numbers and projections of animal productivity (i.e. meat production per animal)
Beef farming	MPI	Emissions from beef cattle based on projected animal numbers and projections of animal productivity (i.e. meat production per animal)
Other farming	MPI	Includes emissions from minor livestock species, fertiliser use and crop burning
Road transport	MoT	Emissions from road transport activity, including EV uptake and fuel use savings assumptions
Air transport	MoT	Domestic aviation
Commercial buildings	EECA	Economic potential energy saving
Industrial buildings	EECA	Economic potential energy saving
Residential buildings	EECA	Economic potential energy saving
Energy mix	MBIE	Mixed renewables electricity generation

Source: NZIER

25 Note that we did not explicitly include EECA’s economywide energy savings into our baseline. This is because they overlap with some of the other projections on specific sectors’ emissions that we obtained from other agencies. Rather, we used these estimates as a sense-check on the energy efficiency gains that we have built into the baseline based on historical data from Statistics New Zealand.

We focus our refinements on aligning our model's emissions projections with those suggested by agencies, and building in any energy efficiency trends by industry that these projections indicate.

We also incorporate industry-specific energy efficiency trends for other industries based on historical trends from 1990-2015, as presented in Statistics New Zealand's recently-released Environmental-economic accounts (Statistics New Zealand, 2018).

A.3.2 EV assumptions

We build a significant uptake of EVs into our baseline scenario. Drawing on analysis from MoT[26] and on previous work by Infometrics (Infometrics 2017), we assume EV uptake rises to be 65% of the light vehicle fleet by 2050. This equates to around a 70% fuel saving over current levels for households.

This has a material impact on the emissions profile, reducing net emissions by around 12Mt CO2-e (or 12%) by 2050 compared to a scenario where we do not explicitly model such an uptake.

We consider alternative EV uptake curves in the scenario analysis.

A.3.3 The role of forestry

As with previous CGE modelling exercises looking at the macroeconomic impact of climate change policies in New Zealand, the impacts of sequestration by the forestry sector are determined outside of the CGE model, rather than being endogenously determined.

That is, in the baseline we take existing midpoint net emissions projections provided by MPI for 2021-2050 and impose them on the emissions baseline, rather than letting the model produce them.[27]

While it would be desirable to have forestry emissions linked to the carbon price within the model, uncertainties over rotation lengths, the mix of trees to be planted and UNFCCC forestry rules make this impractical given the time and resources available for this project.

The baseline forestry emissions profile assumes:

- Carbon prices in the range of $12.50 to $25
- Average annual rate of deforestation of around 4,300 hectares
- Average annual rate of afforestation of around 10,400 hectares
- From 2017 onwards, the species composition is 80% pine and 20% natural reversion/regeneration
- Post-1989 forest rotation ages of around 30 years.

The annual forestry emissions profile used in our baseline is shown in Appendix B.

Note that the baseline does <u>not</u> incorporate the government's plan to plant one billion trees over the next decade. This is because policy details on the plan were not available

[26] See http://www.transport.govt.nz/assets/Uploads/Research/Documents/GOTO-Future-State-A4.pdf for more detail behind these assumptions. The uptake trend to 2040 has been assumed to continue to 2050.

[27] For the 2017-2020 period, we hold the ratio of gross to net emissions constant at 2021 levels.

at the time of developing our baseline. We explore the impact of significantly higher afforestation in our scenario analysis.

In the scenario analysis, we increase our sequestration estimates above MPI's mid-point estimates. Initial modelling runs indicate that meeting 2050 emissions targets in the range being proposed will require a carbon price much higher than the $12.50-25 assumed by MPI and incorporated into our baseline.

It is reasonable to expect that a higher carbon price will result in greater sequestration. As a consequence, and after consultation with officials, we impose the following sequestration estimates, drawing on Vivid, Concept and Motu (2018):

- 50% target: 25Mt sequestration by 2050
- 75% target: 35Mt
- ZNE target: 50Mt.

We assume a linear sequestration pathway to 2050 for each target in all scenarios. We recognise that this is a simplification, but our model is not designed to explore forestry rotation.

In addition, we acknowledge that our treatment of forestry is somewhat circular. Imposing a greater sequestration figure on the economy will reduce the carbon price required to meet a given target, *ceteris paribus*. This will in turn reduce the incentive for greater forestry planting, which will push the rest of the economy harder to meet the target and push up carbon prices. However, in lieu of endogenising forestry to the carbon price, we believe our treatment of forestry is reasonable.

A.3.4 Carbon prices and ETS assumptions

Because many New Zealand industries are exposed to emissions pricing through the Emissions Trading Scheme (ETS), we need to include a carbon price in our emissions baseline.

Based on discussions with officials, we assume in our emissions baseline:

- a real carbon price of NZ$20
- Free Allocation to emissions-intensive and trade-exposed industries that reduces by 1% per year to 2030, then 4% per year out to 2050, based on our assumption that the rest of the world also takes action to address climate change (see next section)[28]
- Biological emissions remain excluded.

We adjust these in some scenarios to reflect potential changes around agriculture.

A.3.5 Assumptions on rest of world action on climate change

Projecting the breadth and depth of global actions to combat climate change out to 2050 is challenging. However, since we are using a single country model for

[28] The phase-out profile is based on the assumption that trade-exposed, emissions-intensive firms will require assistance in the short term while competitors in other countries do not face the full cost of their emissions as these countries start to implement their INDCs. In the longer term, as these targets start to become more ambitious and more industries in more countries are exposed to a carbon price, the competitiveness risk decreases more rapidly, and free allocation is not required to such a great extent in New Zealand.

Workstream 1, we do not have to make predictions about which specific countries will take action, and how much contribution they will make to limiting climate change.

Rather, we need to decide whether the rest of the world's (ROW) actions will have a material impact on New Zealand's export competitiveness.

If ROW action is 'weak', then we would expect New Zealand's export competitiveness to suffer somewhat as many industries are facing the costs of their emissions in New Zealand, when other competitors are not.

If ROW action is 'strong', then our competitors will also face the cost of their emissions, and New Zealand's export competitiveness will not be materially affected.

In our baseline, and based on discussions with officials, we choose ROW action to be 'strong', which could be seen as them meeting their UNFCC Intended Nationally Determined Contributions (INDCs) as per the Paris Agreement.

From a modelling perspective, we hold New Zealand's terms of trade fixed in our baseline scenario, so that New Zealand's domestic policy actions to address climate change do not lead to policy-driven changes in our export (and import) prices. This can be seen as a scenario where New Zealand's carbon price is the same as the price faced by ROW.

In the 'strong' ROW scenario, we phase out ETS free allocation by 1% per year to 2030, then 4% per year out to 2050.

We consider a 'weak' ROW action in the scenario analysis, in which free allocation is retained at existing levels.

A.3.6 Access to international emissions units

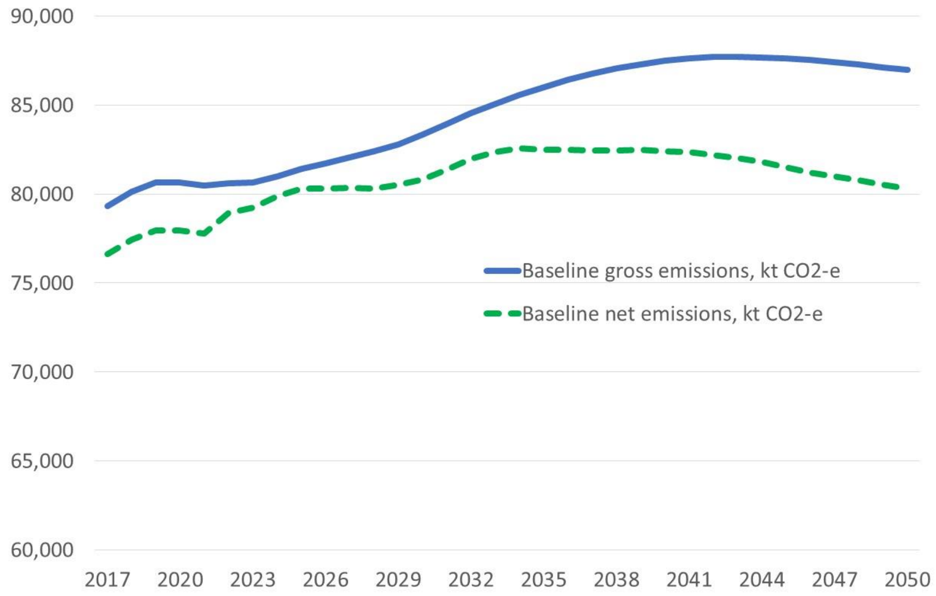
In the baseline, we assume New Zealand does not have access to international units to offset our emissions and meet any given climate change target. That is, all emissions abatement must happen domestically.

We explore the economic impacts of allowing access to international units in our scenario analysis.

A.4 Overview of emissions baseline

Figure 34 Baseline emissions projection

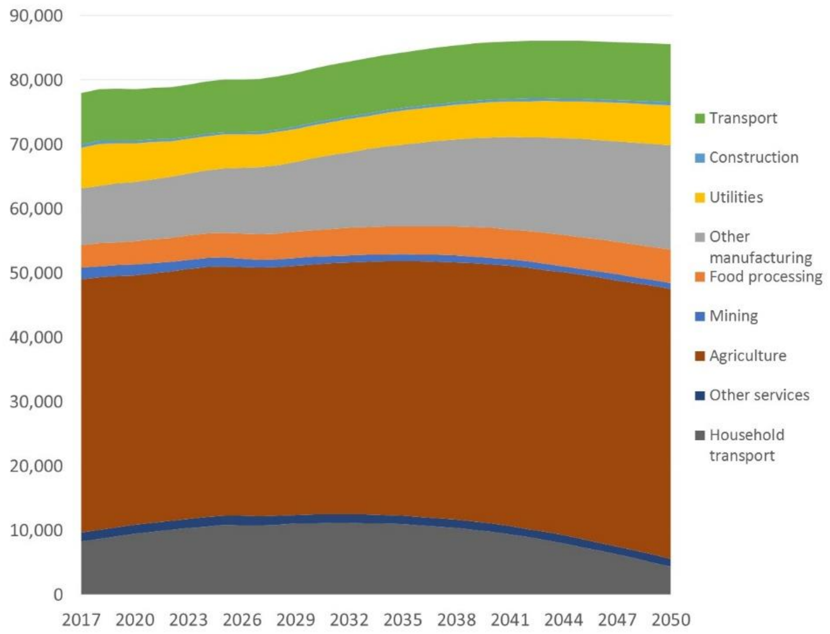
Kt CO_2-e



Source: NZIER

Figure 35 Emissions by broad sector in baseline projection

Kt CO_2-e



Source: NZIER

As these charts show, under the assumptions outlined above, our baseline, which includes strong ROW action, projects gross emissions to reach 87.0Mt CO2-e by 2050, a 9.7% increase on 2017 levels.

Net emissions, which take into account MPI's forestry net sequestration at a low carbon price, are projected to rise from 76.6Mt CO2-e in 2017 to 80.3Mt CO2-e in 2050 (4.8% increase).

The emissions intensity of the economy (i.e. emissions per unit of GDP) is projected to fall by an average of 1.9% per year between 2017 and 2050. This is broadly in line with historical trends – emissions intensity fell by an average of 2.2% per year between 1990 and 2015 (Statistics New Zealand, 2018).

Figure 36 shows emissions intensity trends from 1990 to 2015 and those from our baseline projections. While there are some small differences in trends in some industries, a straight comparison is complicated by the fact that different technological advances and policy settings are covered by the historical and projected periods.[29]

It could be argued that reducing that intensity in the future will be harder as the cheaper and simpler abatement options have already occurred, leaving only more expensive options available. However, one could also argue that technological change, even in the baseline, will likely speed up in the future.

Figure 36 Historical and projected emissions intensity by industry

Compound average growth rates in emissions per unit of GDP

Labels above bars are 2015 shares of economy-wide CO2-e emissions

Source: NZIER, Statistics New Zealand (2018)

29 Note that in this chart, 'Transport' refers to the industry that produces transport services, rather than all transport that includes household use of private vehicles. In our baseline, most of the emissions improvements come through the uptake of EVs by households rather than through significant changes in heavy vehicle fleet composition or energy efficiency.

The Food processing industry's emissions intensity increased by 0.2% per year between 1990 and 2015. This is likely due to a shift in the composition of activities within this grouping towards more emissions-intensive sectors.

'Other manufacturing' in Figure 36 is an aggregation of a wide range of manufacturing industries from our database.30 The emissions intensity of this aggregate industry increased slightly between 1990 and 2015. Decreased in intensity came from Transport equipment, machinery, and equipment manufacturing (-3.7% per year), Furniture and other manufacturing (-5.5% per year) and Non-metallic mineral product manufacturing (-1.0% per year).

But these decreases in intensity were more than offset by increased emissions intensity in Petroleum, chemical, polymer, and rubber product manufacturing (+2.0% per year; accounting for 38% of 'Other manufacturing' emissions in 2015) and Metal product manufacturing (+0.2% per year; accounting for 31%) since 1990 (Statistics New Zealand, 2018).

'Other services' similarly covers many commercial, government and household-related services industries in our database.[31] Its emissions intensity fell sharply between 1990 and 2015, by -2.9% per year (Statistics New Zealand, 2018), although there is no data available on which specific services industries have caused this trend.

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30 Textile and leather manufacturing; Clothing, knitted products, and footwear manufacturing; Wood product manufacturing; Pulp, paper, and converted paper product manufacturing; Printing; Petroleum and coal product manufacturing; Basic chemical and basic polymer manufacturing; Fertiliser and pesticide manufacturing; Pharmaceutical, cleaning, and other chemical manufacturing; Polymer product and rubber product manufacturing; Non-metallic mineral product manufacturing; Primary metal and metal product manufacturing; Fabricated metal product manufacturing; Transport equipment manufacturing; Electronic and electrical equipment manufacturing; Machinery manufacturing; Furniture manufacturing; Other manufacturing.

31 Basic material wholesaling; Machinery and equipment wholesaling; Motor vehicle and motor vehicle parts wholesaling; Grocery, liquor, and tobacco product wholesaling; Other goods and commission based wholesaling; Motor vehicle and motor vehicle parts retailing; Fuel retailing; Supermarket and grocery stores; Specialised food retailing; Furniture, electrical, and hardware retailing; Recreational, clothing, footwear, and personal accessory retailing; Department stores; Other store based retailing; non-store and commission based retailing; Accommodation; Food and beverage services; Postal and courier services; Transport support services; Warehousing and storage services; Publishing (except internet and music publishing); Motion picture and sound recording activities; Broadcasting and internet publishing; Telecommunications services; Library and other information services; Banking and financing; financial asset investing; Life insurance; Health and general insurance; Superannuation and individual pension services; Auxiliary finance and insurance services; Rental and hiring services (except real estate); non-financial asset leasing; Residential property operation; Non-residential property operation; Real estate services; Owner-occupied property operation; Scientific, architectural, and engineering services; Legal and accounting services; Advertising, market research, and management services; Veterinary and other professional services; Computer system design and related services; Travel agency and tour arrangement services; Employment and other administrative services; Building cleaning, pest control, and other support services; Local government administration services; Central government administration services; Defence; Public order, safety, and regulatory services; Preschool education; School education; Tertiary education; Adult, community, and other education; Hospitals; Medical and other health care services; Residential care services and social assistance; Heritage and artistic activities; Sport and recreation services; Gambling activities; Repair and maintenance; Personal services; domestic household staff; Religious services; civil, professional, and other interest groups.

A.5 Baseline summary: what's in, what's out?

Table 24 Summary of Workstream 1 baseline emissions assumptions

Included	Excluded
Specific projections for forestry, transport, agriculture and energy sectors to align with official data	Adjustment to 2030 emissions target
Existing ETS policy settings, including no pricing of biological emissions	Endogenous technological change
Energy efficiency improvements based on historical trends	Disruptive technological change (beyond EV uptake)
Strong ROW action on climate change	Physical impacts of climate change
Phased down Free Allocation	Carbon Capture and Storage
$20 carbon price	Access to international emissions units
EV uptake to 65% of light vehicle fleet by 2050	

Source: NZIER

Many of the items excluded from the baseline are explored in the scenario design and modelling.

Appendix B Forestry assumptions in baseline

Table 25 Forestry's contribution to 2050 target, baseline scenario

CO2-e kt

Year	Net emissions
2017	-2,665
2018	-2684
2019	-2695
2020	-2699
2021	-2,700
2022	-1,700
2023	-1,400
2024	-1,100
2025	-1,100
2026	-1,400
2027	-1,700
2028	-2,100
2029	-2,300
2030	-2,500
2031	-2,600
2032	-2,600
2033	-2,700
2034	-3,000
2035	-3,500
2036	-3,900
2037	-4,300
2038	-4,600
2039	-4,800
2040	-5,100
2041	-5,300
2042	-5,500
2043	-5,700
2044	-5,900
2045	-6,100
2046	-6,300
2047	-6,400
2048	-6,500
2049	-6,600

Source: MPI projections

Appendix C Industry emissions assumptions

Agricultural emissions assumptions

Table 26 Farming assumptions

Animal numbers (millions); kt CO2-e

Industry	Animal population, millions				Emissions			
	1995	2015	2030	2050	1995	2015	2030	2050
Dairy cattle	3.44	6.49	6.92	6.50	7,910	18,070	20,322	20,168
Sheep	57.85	29.12	21.22	21.20	7,054	6,396	6,139	6,083
Beef cattle	4.59	3.55	3.53	3.50	16,249	10,134	7,692	7,896
Other	-	-	-	-	1,910	3,821	3,584	3,585
Total	**-**	**-**	**-**	**-**	**33,123**	**38,420**	**37,737**	**37,732**

Source: MPI

The projections to 2030 were constructed by MPI using forecasts of land-use, population and productivity from the PSRM model. Exogenous forecasts of forest area are used to model the effect of the ETS on agriculture. Animal numbers and fertiliser use have been adjusted to consider the effect of the National Policy Statement for Freshwater Management.

Fertiliser use is assumed to decline slightly to be 5% lower than 2015 levels by 2030. This relative decline occurs linearly between 2016 and 2030.

Past 2030, the projections incorporate assumptions around animal population and productivity. Key assumptions include:

- Per cow milk production, per beef animal production and per sheep/lamb meat production all assumed to hold steady at 2030 levels out to 2050.
- Lambing percentage assumed to be 8% greater than 2030 levels by 2050, changing linearly.
- Fertiliser use is assumed constant after 2031.

Energy efficiency assumptions

We used energy efficiency data from EECA to cross-check the emissions-intensity improvements in our baseline.

These are summarised below in Table 27. The projected economy-wide efficiency improvement of 0.69% per year out to 2050 is within the range of the improvements incorporated into our baseline.

Table 27 Energy efficiency assumptions

Energy PJ

Building type	Fixed technology demand	Potential saving	Average improvement pa
Residential	90.4	27.9	1.11%
Commercial	149.9	55.6	1.41%
Industrial	409.9	48.6	0.38%
Total	**650.2**	**132.1**	**0.69%**

Source: EECA

Appendix D Industry aggregation

Table 28 Mapping of input-output table industries into 15 broad aggregate industries

Input-output tables industry	Aggregated industry
Horticulture and fruit growing	Horticulture
Sheep, beef cattle, and grain farming	Sheep and beef
Dairy cattle farming	Dairy cattle
Poultry, deer, and other livestock farming	Other primary
Forestry and logging	Other primary
Fishing and aquaculture	Other primary
Agriculture, forestry, and fishing support services	Other primary
Coal mining	Mining
Oil and gas extraction	Mining
Metal ore and non-metallic mineral mining and quarrying	Mining
Exploration and other mining support services	Mining
Meat and meat product manufacturing	Meat manufacturing
Seafood processing	Food processing
Dairy product manufacturing	Dairy product
Fruit, oil, cereal, and other food product manufacturing	Food processing
Beverage and tobacco product manufacturing	Food processing
Textile and leather manufacturing	Other manufacturing
Clothing, knitted products, and footwear manufacturing	Other manufacturing
Wood product manufacturing	Other manufacturing
Pulp, paper, and converted paper product manufacturing	Other manufacturing
Printing	Other manufacturing
Petroleum and coal product manufacturing	Petroleum, chemicals
Basic chemical and basic polymer manufacturing	Petroleum, chemicals
Fertiliser and pesticide manufacturing	Petroleum, chemicals
Pharmaceutical, cleaning, and other chemical manufacturing	Petroleum, chemicals
Polymer product and rubber product manufacturing	Petroleum, chemicals
Non-metallic mineral product manufacturing	Other manufacturing
Primary metal and metal product manufacturing	Other manufacturing
Fabricated metal product manufacturing	Other manufacturing
Transport equipment manufacturing	Machinery
Electronic and electrical equipment manufacturing	Machinery
Machinery manufacturing	Machinery
Furniture manufacturing	Other manufacturing
Other manufacturing	Other manufacturing
Coal electricity generation and on-selling	Utilities
Gas electricity generation and on-selling	Utilities
Oil electricity generation and on-selling	Utilities
Hydro electricity generation and on-selling	Utilities
wind electricity generation and on-selling	Utilities
Geithermal electricity generation and on-selling	Utilities
Electricity transmission and distribution	Utilities
Gas supply	Utilities
Water supply	Utilities
Sewerage and drainage services	Utilities
Waste collection, treatment, and disposal services	Utilities
Residential building construction	Construction
Non-residential building construction	Construction
Heavy and civil engineering construction	Construction
Construction services	Construction
Accommodation	Accomodation, food and beverage services
Food and beverage services	Accomodation, food and beverage services
Road transport	Transports
Rail transport	Transports
Other transport	Transports
Air and space transport	Transports
Basic material wholesaling	Wholesaling, retailing
Machinery and equipment wholesaling	Wholesaling, retailing
Motor vehicle and motor vehicle parts wholesaling	Wholesaling, retailing
Grocery, liquor, and tobacco product wholesaling	Wholesaling, retailing
Other goods and commission based wholesaling	Wholesaling, retailing
Motor vehicle and motor vehicle parts retailing	Wholesaling, retailing
Fuel retailing	Wholesaling, retailing
Supermarket and grocery stores	Wholesaling, retailing
Specialised food retailing	Wholesaling, retailing
Furniture, electrical, and hardware retailing	Wholesaling, retailing
Recreational, clothing, footwear, and personal accessory retailing	Wholesaling, retailing
Department stores	Wholesaling, retailing
Other store based retailing; non-store and commission based retailing	Wholesaling, retailing
Postal and courier services	Other services
Transport support services	Other services
Warehousing and storage services	Other services
Publishing (except internet and music publishing)	Other services
Motion picture and sound recording activities	Other services
Broadcasting and internet publishing	Other services
Telecommunications services	Other services
Library and other information services	Other services
Banking and financing; financial asset investing	Other services
Life insurance	Other services
Health and general insurance	Other services
Superannuation and individual pension services	Other services
Auxiliary finance and insurance services	Other services
Rental and hiring services (except real estate); non-financial asset leasing	Other services
Residential property operation	Other services
Non-residential property operation	Other services
Real estate services	Other services
Owner-occupied property operation	Other services
Scientific, architectural, and engineering services	Other services
Legal and accounting services	Other services
Advertising, market research, and management services	Other services
Veterinary and other professional services	Other services
Computer system design and related services	Other services
Travel agency and tour arrangement services	Other services
Employment and other administrative services	Other services
Building cleaning, pest control, and other support services	Other services
Local government administration services	Other services
Central government administration services	Other services
Defence	Other services
Public order, safety, and regulatory services	Other services
Preschool education	Other services
School education	Other services
Tertiary education	Other services
Adult, community, and other education	Other services
Hospitals	Other services
Medical and other health care services	Other services
Residential care services and social assistance	Other services
Heritage and artistic activities	Other services
Sport and recreation services	Other services
Gambling activities	Other services
Repair and maintenance	Other services
Personal services; domestic household staff	Other services
Religious services; civil, professional, and other interest groups	Other services

Source: NZIER