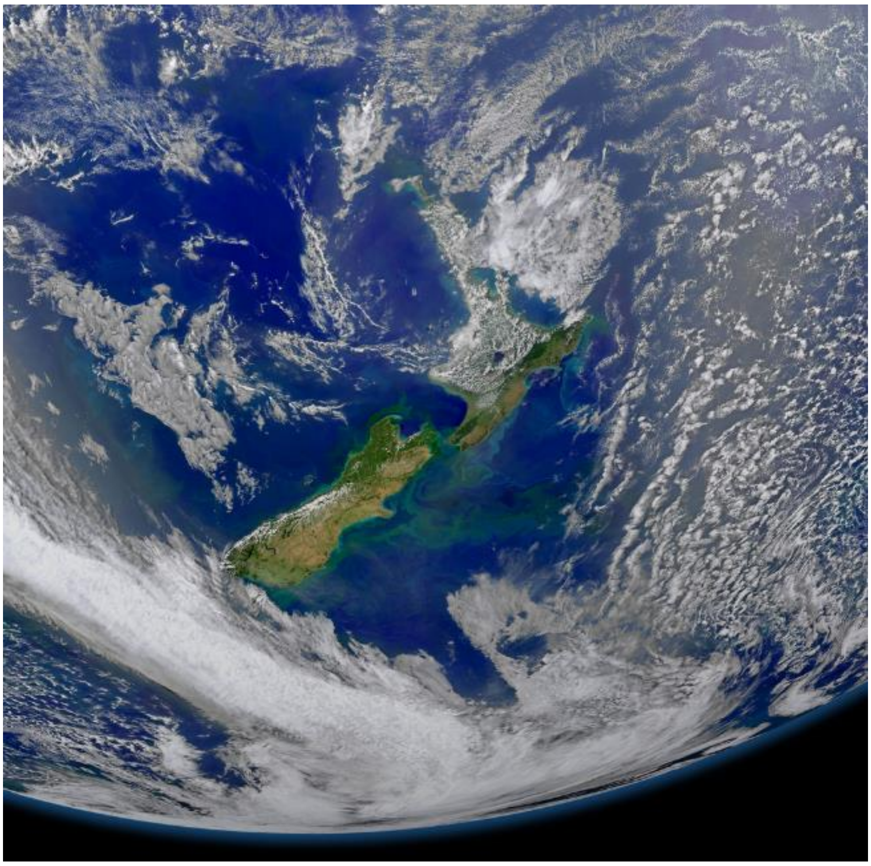
Modelling the transition to a lower net emissions New Zealand

Uncertainty analysis

July 2018



:vivideconomics

concept

Motu
Motu Economic and Public Policy Research

Contents

List of tables

List of figures

1. Key findings

This analysis augments the results previously presented alongside the Productivity Commission's draft report. It focuses on the implications of policy and investment choices made in the coming decade for the long-term performance of New Zealand's economy and emissions outcomes, accounting for significant uncertainties regarding technological and market developments. In doing so it updates assumptions from the interim report,[1] and considers how policy and investment strategies may perform, when circumstances develop in unanticipated ways.

For clarity, this uncertainty analysis is presented separately, however it is intended to build on, and enhance understanding of, the findings outlined in the interim report. Many of the findings, discussed below, reinforce those developed in the interim report; however, the analysis allows richer conclusions to be reached about strategies for managing the low-carbon transition.

Emissions reductions from a range of sources remain important regardless of how future uncertainties are resolved. Across all future states of the world examined, the lowest-cost mitigation pathways draw on emissions reductions from a mixture of transport, other energy and industry, agriculture, and forestry sectors. This suggests that a portfolio of mitigation sources is beneficial and reflects the fact that there are cost-effective emissions-reductions actions across all sectors – albeit to varying degrees.

Stronger government action in the near term can constrain future carbon costs, while delayed action may result in higher prices. Regardless of the future state of the world, the 2050 emissions prices required to meet the 25 $MtCO_2e$ target[2] are lowest in scenarios which feature stronger government action in the near term (Policy-driven), in the form of a higher emissions price to 2030 and policies such as significant support for native afforestation. Higher pre-2030 emissions prices mean that investment in capital that will have a lifetime of decades (such as new vehicles and new industrial process heat boilers) will tend to be lower emissions. Similarly, gradual expansion of forestry throughout the period is likely more achievable and lower cost than a very rapid increase in planting to high rates at the end of the period. In contrast, the scenarios with higher emissions to 2030 and lower emissions prices (Stabilising decarbonisation) require the highest 2050 emissions price to reach the target. These scenarios feature a slower rate of structural change with higher emissions to 2030. However, not all types of early action may be appropriate. Some irreversible decisions may cause higher economic costs; for instance, while aluminium smelting is exogenously assumed to close in the Disruptive decarbonisation scenarios, it appears to remain viable under the broad set of assumptions used.

---

[1] See Concept Consulting, Motu Economic and Public Policy Research, & Vivid Economics. 2018. Modelling the transition to a lower net emissions New Zealand: Interim results. Wellington: New Zealand Productivity Commission. Available at https://www.productivity.govt.nz/inquiries/lowemissions/

[2] $MtCO_2e$ stands for million tonnes of carbon dioxide equivalent – this is the international standard metric for aggregating greenhouse gases based on their warming potential over a hundred-year timeframe.

The scale of land-use change is modest in all future states of the world, but in some cases occurs rapidly. The overall expansion of forestry required in each scenario is well within the scale of change identified by previous studies. In some circumstances – particularly if expectations of rapid technological change are not realised – delivering this expansion may be challenging, as planting rates far exceed those achieved in the past. If these planting rates could not be delivered due to practical barriers not represented in the model, higher emissions prices would be needed to drive deeper decarbonisation in other sectors.

The differences between scenarios are in part driven by the high degree of sensitivity of land-use decisions to relatively small shifts in commodity prices. Variants use a range of agriculture and forestry prices, with shifts in relative prices well within the range of historical experience. Nonetheless, these small changes drive large changes in land-use decisions. While the land sector can provide significant mitigation, the high degree of sensitivity of land-use change to agricultural and forestry commodity prices suggests that further research into the economics of land-use decisions would assist in developing policies to enable this investment.

Should disruptive technological change and associated market conditions after 2030 materialise, New Zealand's emissions-reduction targets may be achieved at very low cost. In the states of the world in which innovation disrupts existing industries from 2030, an emissions price reaching just over NZ$50 by 2050 would over-deliver the 25 $MtCO_2e$ target assumed for this modelling.[3] In the other states of the world considered, emissions prices of between NZ$118 and NZ$224 in 2050 are required to meet this target.

Slow international action has only minor implications for the costs, but competitiveness impacts need to be managed. When tested in a world featuring slow international action, production and emissions outcomes in New Zealand are comparable to those in a Paris-consistent world. However, the closure of iron and steel capacity in one of the Slow-international-action variants underlines the ongoing need for free allocations in the New Zealand Emissions Trading Scheme (NZ ETS) to be well managed to offset potential competitive effects.

This modelling also presents a sensitivity analysis, which tests the robustness of conclusions to higher rates of population growth and higher rates of industry allocations. It finds that increased population growth leads to higher energy and transport emissions, but that these sensitivities have little impact on the emissions prices needed to reach targets, or the allocation of emissions reductions across different sectors.

---

[3] Results were developed by interpolating a finite number of modelling runs for each scenario – the Disruptive variant outperformed the 25 $MtCO_2e$ target for the lowest-price modelling run in each scenario.

2. Methodology

In addressing climate change, New Zealand collectively will make decisions regarding how to pursue its interests in a changing domestic and international environment. When certain expectations are common across society, this results in a consistent pattern of decisions that can be interpreted as *scenarios*. These scenarios feature policies and investment decisions that will affect economic performance. Scenarios can be used to represent the different decisions that New Zealand could make, and allow them to be modelled and tested, to see how they may perform against outcomes of interest, such as economic activity and greenhouse gas emissions.

Scenarios encapsulate the idea that government and private agents can choose from a set of strategies based on their preferences (e.g. regarding time, risk, and distribution) and their subjective assessment of the probabilities of future events. For instance, the choice by a landowner of whether to convert a harvested forest to dairy production will be a function of not only current policies and commodity prices but also expectations of future changes. Similarly, investment in new electricity generation, and the future of emissions-intensive manufacturing, responds to expectations regarding future demand, prices, and technological developments.

In choosing its policy mix, the government also responds to these influences. Expectations regarding future commodity demand, for example, will inform its economic strategy, and reform of market and institutional structures may be pursued if needed to deliver expected technological changes. The government's policy stance also reflects social preferences; for instance, greenhouse gases vary in their impact on the climate over time, so preferences regarding intertemporal welfare trade-offs may result in different approaches to short- and long-lived greenhouse gases.

However, the performance of scenarios depends on uncertainties outside of any individual's or group's control. The performance of strategies (as encapsulated in a scenario) may deviate from the expected performance due to uncertainty regarding key variables. A set of strategies that is the best in one realisation of the future state of the world may not be in another. The purpose of this analysis is to explore how different decarbonisation scenarios perform against a range of exogenous uncertainties including:

- the speed and nature of technological change
- fossil fuel and commodity prices
- international emissions prices

In general, rapid technological change will decrease global mitigation costs; however, the specific nature of this change can result in different impacts across industries. For instance, in the agricultural sector, advancements in the development of meat substitutes would result in accelerated movement away from pastoral agriculture and growth in the production of crops or horticulture. By contrast, development of vaccines to reduce the production of methane by livestock would increase the competitiveness of pastoral agriculture relative to alternative land-uses. In the transport sector, increased internal combustion engine (ICE) fuel efficiency could prolong the use of ICE vehicles, while rapid improvements in electric vehicles (EVs) and reductions in their cost could accelerate the transition away from fossil fuels.

The global prices of oil and other commodities are a key uncertainty that will determine the level of production in trade-exposed industries, such as agriculture, forestry and manufacturing. New Zealand acts as a price-taker in most tradeable goods markets, making its economic performance closely linked to commodity prices. Fossil fuel prices also play an important role in determining the competitiveness of different generation assets and transport technologies.

Relative emissions prices can be a key determinant of production costs between jurisdictions. These differences in emissions prices could drive shifts in patterns of production between countries, resulting in 'carbon leakage'. Carbon leakage occurs when a reduction in production in one country, caused by a higher relative carbon cost, means it is replaced by more polluting production in another. While there is little evidence of carbon leakage to date, this remains a significant policy concern, particularly at higher emissions prices.

This modelling provides a simplified representation of the future by differentiating between two periods. It presents three scenarios for how the world may develop to 2030, at which point circumstances could change dramatically, and the New Zealand government, businesses and individuals adjust to these new conditions.

It assumes that in the first period, between 2015 and 2030, governments and individuals make policy and investment choices based on a known economic environment. Then from 2030 this economic environment could change, specifically regarding fossil fuel prices, international emissions prices and the speed and type of technological change. Agents respond to these changed circumstances, but the way in which they can do so is affected by the combinations of choices, and technological and price outcomes realised in the 2015–30 period. In the language of the report, the choices and associated outcomes made in 2015–30 define the 'scenarios' while the different states of the world that could emerge in the 2030–50 period define the 'uncertainty variants'. We compare the attractiveness of each 2015–30 scenario in reaching a 25 $MtCO_2e$ emissions-reduction target by 2050, accounting for the uncertainty variants that are realised beyond 2030.

The three scenarios determining outcomes in the period to 2030 are:

- **Policy-driven**; this scenario sees slow, sector-neutral, technological change which necessitates ambitious policy action, specifically a high emissions price. Commodity prices and rates of technological change are moderate, while government policy drives the expansion of permanent native forestry in the land sector.
- **Disruptive decarbonisation**; this scenario features rapid technological change that disrupts current economic structures, with new technologies and products creating new markets, destroying demand in traditional industries and accelerating capital turnover. Technological change occurs rapidly, driving the expansion of EVs and renewables. Some energy- and carbon-intensive facilities decide to close in anticipation of changing global outlook, while change in the energy sector is accelerated through policy or investment decisions to close some fossil fuel capacity.
- **Stabilising decarbonisation**; this scenario features optimistic expectations regarding the potential for rapid technological change that stabilises existing industry structures through the emergence of new mitigation options, such as methane vaccines and nitrogen

inhibitors, that would reduce the need for large shifts in economic activity. In contrast other technological change is slower, with the expansion of EVs in the transport sector taking longer than other scenarios. Current industry structures are further supported through relatively generous industry assistance rates.

We explore the attractiveness of each of these pre-2030 scenarios in four different post-2030 uncertainty variants:

- **Moderate technological change**; this represents a future that aligns with the Policy-driven scenario.
- **Innovation disrupting existing industries**; this represents a future that aligns with the Disruptive decarbonisation scenario.
- **Innovation supporting existing industries**; this represents a future that aligns with the Stabilising decarbonisation scenario.
- **Slow international action**; this represents a future where countries' action falls short of that envisioned under the Paris Agreement, resulting in slower rates of technological change across the board, and higher prices for emissions-intensive goods. In response to this, government maintains higher levels of allocations for trade-exposed industries.

Like all modelling, this uncertainty analysis has limitations. Its ability to capture the impact of uncertainty to 2030 is limited as we assume policy and investment decisions align with reality, while after 2030 the relative performance of different scenarios is tested against only a limited range of potential outcomes. As such, this modelling should be seen as the first stage of an ongoing process of adaptive policymaking that responds to and integrates new information as it arises.

Table 1 below shows the combinations of scenarios and variants; Table 2 outlines the assumptions regarding key price, technology and policy and investment choices in these scenarios; and Table 3 defines these as specific assumptions.

Table 1. **Scenario variant combinations**

#	Scenario (2015–30)	Variant (2030–50)
1.1	Policy-driven	Moderate technological change
1.2	Policy-driven	Innovation disrupting existing industries
1.3	Policy-driven	Innovation supporting existing industries
1.4	Policy-driven	Slow international action
2.1	Disruptive decarbonisation	Moderate technological change
2.2	Disruptive decarbonisation	Innovation disrupting existing industries
2.3	Disruptive decarbonisation	Innovation supporting existing industries
2.4	Disruptive decarbonisation	Slow international action
3.1	Stabilising decarbonisation	Moderate technological change
3.2	Stabilising decarbonisation	Innovation disrupting existing industries
3.3	Stabilising decarbonisation	Innovation supporting existing industries
3.4	Stabilising decarbonisation	Slow international action

Source : *Concept, Motu, Vivid Economics*

Table 2. **Combinations of scenarios and uncertainties under variants**

		Prices						**Technologies**					**Policies**					
		International emissions price	**Oil price**	**Basic metals price**	**Animal product price**	**Horticulture price/area**	**Forest product price**	**Battery/EV cost reductions**	***ICE efficiency***	**Renewables cost**	**Carbon efficiency**	**Methanogen vaccine/inhibitor**	**ETS free allocations**	**Iron & steel, aluminium***	**Huntly coal and TCC CCGT***	**Public transport**	**Vehicle scrappage rate**	**Native scrub**
1.1	**To 2030**	High	Med	Med	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med	Med	Med	Med	Med
	Post-2030	High	Med	Med	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med	Med	Med	Med	Med
1.2	**To 2030**	High	Med	Med	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med	Med	Med	Med	Med
	Post-2030	Med	Low	Low	Low	High	High	High	Low	Low	Med	Low	Low	Med	Med	High	High	Low
1.3	**To 2030**	High	Med	Med	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med	Med	Med	Med	Med
	Post-2030	Med	High	High	High	Low	Low	Low	High	High	High	High	Med	Med	Med	Low	Low	Low
1.4	**To 2030**	High	Med	Med	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med	Med	Med	Med	Med
	Post-2030	Low	High	High	High	Med	Med	Low	Low	High	Low	Low	High	Med	Med	Med	Med	Low
2.1	**To 2030**	Med	Low	Low	Low	High	High	High	Low	Low	Med	Low	Low	Low	Low	High	High	Low
	Post-2030	High	Med	Med	Med	Med	Med	Med	Med	Med	Med	Low	Low	Low	Low	Med	Med	Med
2.2	**To 2030**	Med	Low	Low	Low	High	High	High	Low	Low	Med	Low	Low	Low	Low	High	High	Low
	Post-2030	Med	Low	Low	Low	High	High	High	Low	Low	Med	Low	Low	Low	Low	High	High	Low
2.3	**To 2030**	Med	Low	Low	Low	High	High	High	Low	Low	Med	Low	Low	Low	Low	High	High	Low
	Post-2030	Med	High	High	High	Low	Low	Low	High	High	High	High	Med	Low	Low	Low	Low	Low
2.4	**To 2030**	Med	Low	Low	Low	High	High	High	Low	Low	Med	Low	Low	Low	Low	High	High	Low
	Post-2030	Low	High	High	High	Med	Med	Low	Low	High	Low	Low	High	Low	Low	Med	Med	Low
3.1	**To 2030**	Med	High	High	High	Low	Low	Low	High	High	High	High	Med	Med	Med	Low	Low	Low
	Post-2030	High	Med	Med	Med	Med	Med	Med	Med	Med	Med	Low	Low	Med	Med	Med	Med	Med
3.2	**To 2030**	Med	High	High	High	Low	Low	Low	High	High	High	High	Med	Med	Med	Low	Low	Low
	Post-2030	Med	Low	Low	Low	High	High	High	Low	Low	Med	Low	Low	Med	Med	High	High	Low
3.3	**To 2030**	Med	High	High	High	Low	Low	Low	High	High	High	High	Med	Med	Med	Low	Low	Low
	Post-2030	Med	High	High	High	Low	Low	Low	High	High	High	High	Med	Med	Med	Low	Low	Low
3.4	**To 2030**	Med	High	High	High	Low	Low	Low	High	High	High	High	Med	Med	Med	Low	Low	Low
	Post-2030	Low	High	High	High	Med	Med	Low	Low	High	Low	Low	High	Med	Med	Med	Med	Low

Note: *CCGT, combined-cycle gas turbine. ICE, internal combustion engine. *Indicates an irreversible decision or policy.*

Source: *Concept, Motu, Vivid Economics*

Table 3. **Variable definitions under high, medium, and low variants**

Variable	High	Medium	Low
Prices			
International carbon	International emissions prices start at NZ$25 in 2018, before increasing to $131 by 2030 and $240 by 2050	International emissions prices start at NZ$25 in 2018, before increasing to $87 by 2030 and $160 by 2050	International emissions prices start at NZ$25 in 2018, before increasing to $38 by 2030 and $70 by 2050
Oil	US$90/bbl	US$75/bbl	US$60/bbl
Animal product	Prices 10 per cent higher than commodity price forecasts from the ‘Situation and Outlook for Primary Industries’ 2017. Prices held constant at this relatively high level beyond 2021, the last projection year of the outlook	Commodity price forecasts from the ‘Situation and Outlook for Primary Industries’ 2017. Prices held constant beyond 2021, the last projection year of the outlook	Prices 10 per cent lower than commodity price forecasts from the ‘Situation and Outlook for Primary Industries’ 2017. Prices held constant at this relatively low level beyond 2021, the last projection year of the outlook
Horticulture price/area	High price leads to linear increase of 25,640 ha per year to 2050	Moderate price leads to linear increase of 12,820 ha per year to 2050	Low price means horticulture land area stays constant
Forest product	Prices 10 per cent higher than commodity price forecasts from the ‘Situation and Outlook for Primary Industries’ 2017. Prices held constant beyond 2021, the last projection year of the outlook	Commodity price forecasts from the ‘Situation and Outlook for Primary Industries’ 2017. Prices held constant beyond 2021, the last projection year of the outlook	Prices 10 per cent lower than commodity price forecasts from the ‘Situation and Outlook for Primary Industries’ 2017. Prices held constant beyond 2021, the last projection year of the outlook
Technology			
Battery/EV cost reductions	Costs decline at 8 per cent per annum	Costs decline at 6 per cent per annum	Costs decline at 4 per cent per annum
ICE efficiency	50 percent faster than historical rate of improvement over the past 15 years	Continuation of historical rate of improvement over the past 15 years	Half the historical rate of improvement over the past 15 years

Variable	High	Medium	Low
Renewables cost	Cost reductions of 1.5 times the rates in the medium variant	Annual cost improvement for wind, solar and geothermal is 1.25 per cent, 2.5 per cent and 0.25 per cent respectively	Cost reductions of 0.5 times the rates in the medium variant
Consumer energy efficiency for gas-using energy needs	The assumed rate of improvement is 0.2 per cent per annum for all uses except residential space heating which is 0.5 per cent per annum	The assumed rate of improvement is 0.1 per cent per annum for all uses except residential space heating which is 0.25 per cent per annum	*NA*
Methanogen vaccine/ inhibitor	Methane vaccine available **after 2030**: reduces dairy livestock emissions by 30 per cent, sheep/beef livestock emissions by 20 per cent, with 100 per cent adoption	*NA*	No vaccine or inhibitor
<u>Investment/policy choices</u>			
ETS free allocations	2015–20, allocation as per NZ ETS for industry, agriculture to receive 95 per cent free. From 2020, assistance withdrawn at 1 percentage point per year	2015–20, allocation as per NZ ETS for industry, agriculture to receive 95 per cent free. From 2020, assistance withdrawn at 3 percentage points per year	2015–20, allocation as per NZ ETS for industry, agriculture to receive 95 per cent free. From 2020, assistance withdrawn at 5 percentage points per year
Iron & steel, aluminium	*NA*	Endogenously modelled based on New Zealand and international emissions prices	Exogenously specified closure in 2025
Huntly coal & TCC CCGT	*NA*	Operation/retirement endogenously modelled based on technology costs, fuel prices, and emissions prices	Exogenously specified closure in 2025
Public transport	75 per cent increase over 30 years in the proportion of trips by public transport, walking, cycling and a 30 per cent increase in the proportion of car-sharing	50 per cent increase over 30 years in the proportion of trips by public transport, walking, cycling and a 20 per cent increase in the proportion of car-sharing	25 per cent increase over 30 years in the proportion of trips by public transport, walking, cycling and a 10 per cent increase in the proportion of car-sharing

Variable	High	Medium	Low
Vehicle scrappage rate	Scrappage rates 50 per cent higher than historical rates	Scrappage rates 25 per cent higher than historical rates	Scrappage rates continue at historical rates
Native scrub	*NA*	Endogenous and exogenous. Exogenous component represents a policy push toward natives amounting to 33 per cent of new forests	Endogenous

Note: *NA is used to note where a definition is not used in any scenario and is therefore not applicable.*
Source: *Concept, Motu, Vivid Economics*

3. Uncertainty analysis results

This modelling focuses on examining how policy and investment choices made in the coming decade affect the long-term performance of New Zealand's economy and emissions outcomes. It seeks to identify which scenarios may perform best in managing the impacts of a low-carbon transition on New Zealand, accounting for substantial global uncertainty. It also develops sensitivity analysis in response to comments on the interim report, considering the impact of varying rates of population growth and different allocation regimes for trade-exposed industries.

In developing a richer analysis of uncertainty, it builds on the interim report by identifying how relative impacts and costs may develop as circumstances change. Table 4 at the end of this section summarises key indicators by scenario and uncertainty variant.

3.1 Performance of scenarios

A key role of this modelling is to provide guidance on the robustness of scenarios to future events. Below we compare how scenarios perform in terms of emissions prices and emissions across the economy, and identify implications for sectors and sources of emissions.

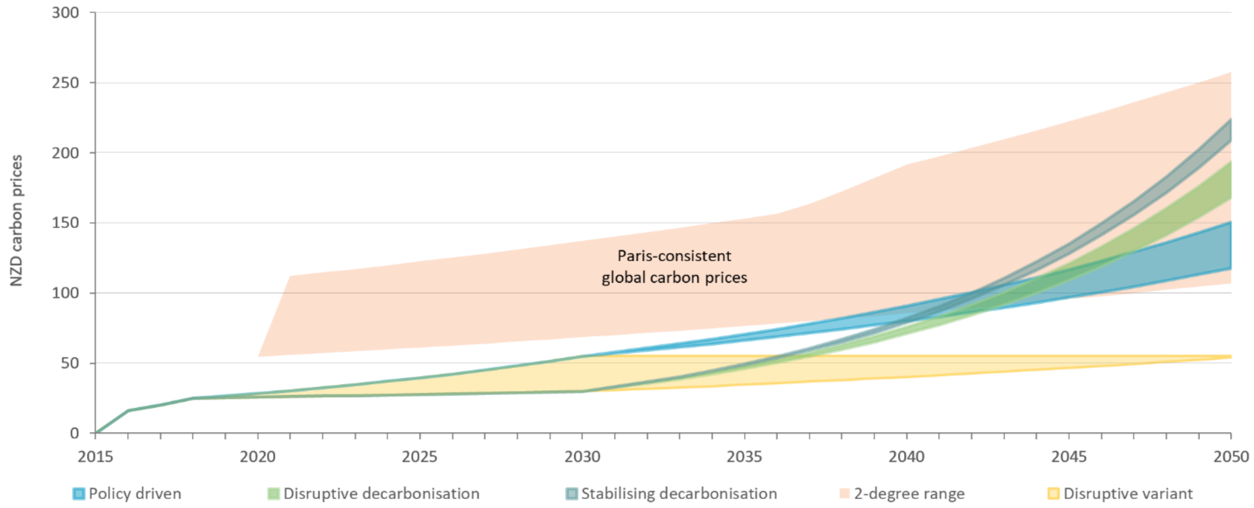
3.1.1 Emissions prices and emissions

The trajectory of emissions prices differs consistently across the scenarios. To 2030, emissions prices are exogenously determined according to the strategies embedded in the different scenarios, with prices increasing more rapidly in the Policy-driven scenarios. After 2030, these prices are free to vary to meet the emissions constraint.

The Policy-driven scenarios deliver the lowest emissions price in 2050 in all uncertainty variants, suggesting benefits to stronger early action, as shown in Figure 1. Further, the real net outlays on emissions units – that is the annual value of net emissions – increase steadily to 2030 and then stay broadly stable at below NZ$4 billion per annum, as shown in Figure 2. These outlays give an indication of how the relative economic costs might differ between scenarios over time, with higher annual outlays suggesting relatively higher economic costs. However, actual economic costs are likely to be lower than that implied by the net outlay on emissions units as resources are anticipated to be redeployed across the economy. Overall this suggests that the Policy-driven scenarios have higher economic costs earlier in the period up to and soon after 2030, but that these costs are lower relative to other scenarios by 2050.

The Disruptive decarbonisation scenarios have higher emissions prices in 2050 than the Policy-driven scenarios, despite lower energy sector emissions from the closure of coal- and some gas-fired generators, and aluminium and steel plants. This appears to be due to low agriculture and high forestry prices in the period to 2030, which results in significant expansion of plantation forestry before 2030, and exhausts much of the lower-cost mitigation available from land-use change before 2050. As such, real net outlays on emissions units increase from a low base in 2030 to reach between NZ$4 billion and NZ$5 billion by 2050 in all but the lowest-cost variant.

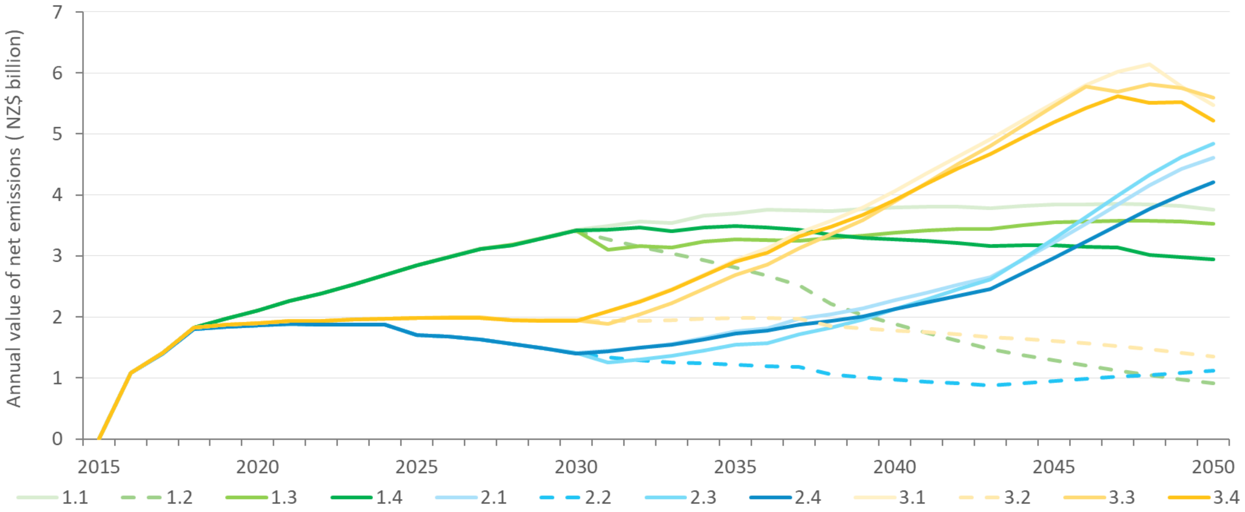
Figure 1. **All scenarios, excluding Innovation-disrupting-existing-industry variants, see emissions prices within Paris envelope**



Note: *The innovation-disrupting-existing-industry variants for each scenario are presented separately in this figure (shown in yellow), as this variant sees the emissions-reduction target being achieved at prices far below Paris-consistent levels.*

Source: *Concept, Motu, Vivid Economics*

Figure 2. **Emissions costs stabilise after 2030 with early action, but rise given a slower start**



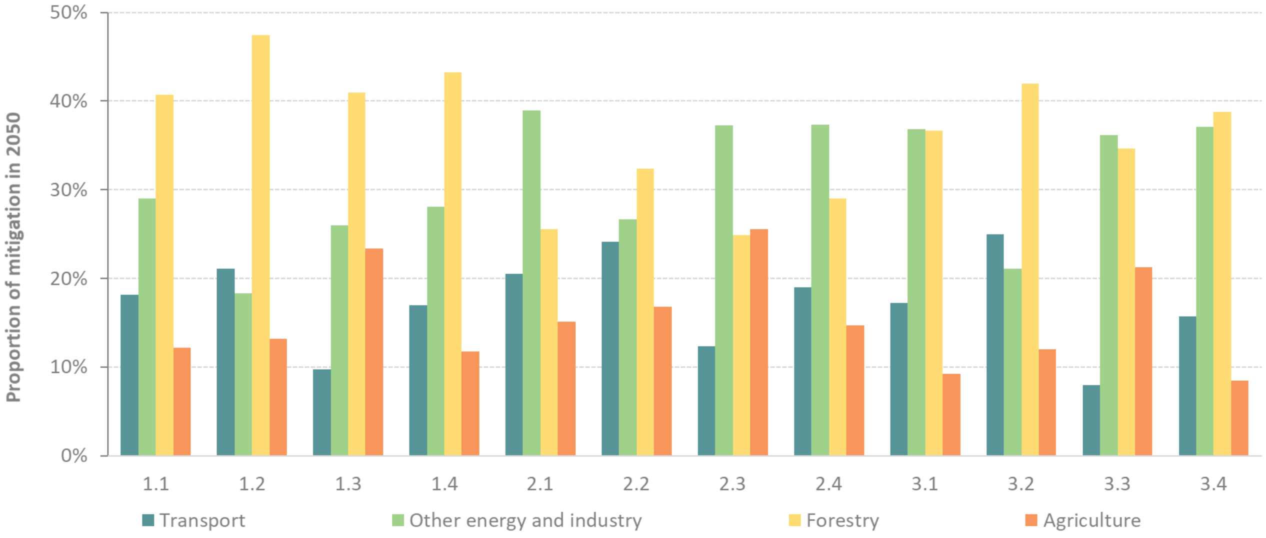
Source: *Concept, Motu, Vivid Economics*

The Stabilising decarbonisation scenarios consistently require the highest 2050 emissions price, with investment lock-in and low rates land-use change meaning that, post-2030, rapid changes are required to accelerate emissions reductions. This also sees real net outlays on emissions units increase most rapidly, rising steadily to between NZ$5 billion and NZ$6 billion by 2050 in all but the lowest-cost variant, after remaining stable throughout the 2020s.

The modelling results suggest that a portfolio of mitigation sources is beneficial, with broad-based policies providing incentives for low-cost emissions reductions across the economy. Figure 3 shows that uncertainty variants utilise emissions reductions from a range of sources with, by 2050:

- transport providing between 8 and 25 per cent of emissions reductions
- other energy and industry providing between 18 and 39 per cent of emissions reductions
- agriculture providing between 8 and 26 per cent of emissions reductions
- forestry providing between 25 and 47 per cent of emissions reductions

Figure 3. **A wide variety of sources contribute to mitigation by 2050 across all uncertainty variants**



Source: *Concept, Motu, Vivid Economics*

While all scenario variants reach the 25 MtCO$_2$e target by 2050, this masks substantial differences in cumulative emissions. Climate change is driven by the accumulation of greenhouse gases. The most common of these, carbon dioxide, and other major greenhouse gases such as nitrous oxide, have a very long atmospheric lifespan once emitted,[4] and as such cumulative emissions from a given scenario are key to understanding long-term climate impacts. Cumulative net emissions are lowest in the Disruptive decarbonisation scenarios (1.5 to 1.6 GtCO$_2$e from 2016–50), reflecting early rapid land-use change driven by commodity price differences,[5] the rapid uptake of EVs, and the closure of major industrial facilities and fossil fuel generators. Conversely, they are at least 25 per cent higher in the Stabilising decarbonisation scenarios (1.9 to 2.0 GtCO$_2$e from 2016–50), reflecting the slower near-term transition away from high-emissions goods and technologies. The Policy-driven scenarios sit in the middle (1.8 to 1.9 GtCO$_2$e from 2016–50) with

---

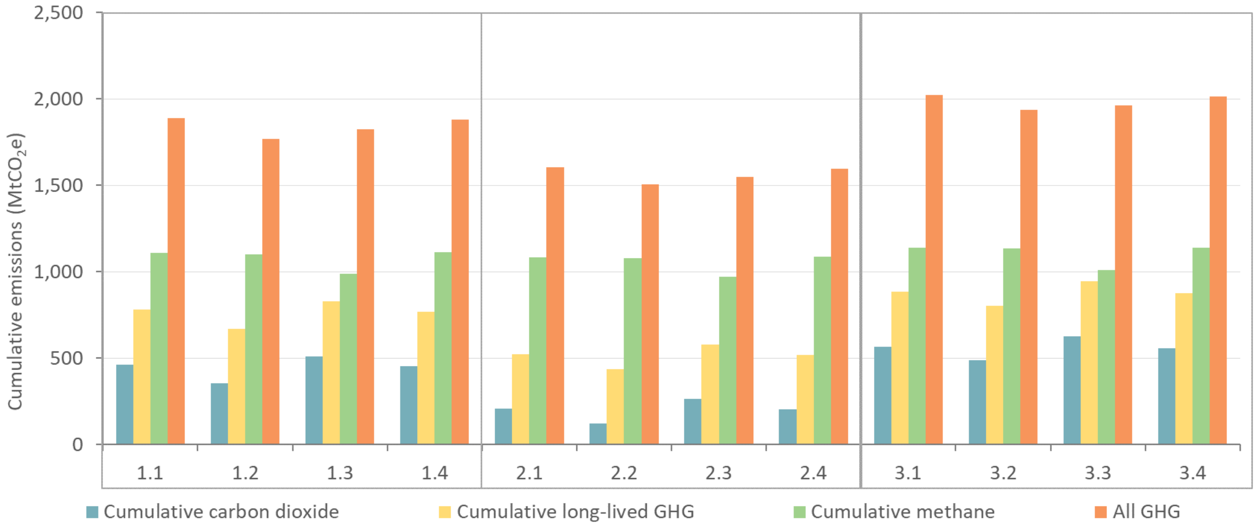
[4] Long-lived pollutants include carbon dioxide and nitrous oxide, whereas methane is considered a short-lived pollutant.

[5] In the interim modelling, only the medium case for agricultural commodity prices was used. The variance in commodity prices including in this modelling has a major impact on land-use decisions and therefore marginal costs of abatement.

higher initial emissions prices and policy support for native afforestation resulting in a gradual rate of emissions reductions.

The composition of cumulative net emissions also reveals substantial differences, with Disruptive decarbonisation scenarios having far lower emissions of carbon dioxide and other long-lived gases. This reflects the slower rates of mitigation from agriculture and the early rapid expansion of forestry. Differences in cumulative emissions by emission type are shown in Figure 4.

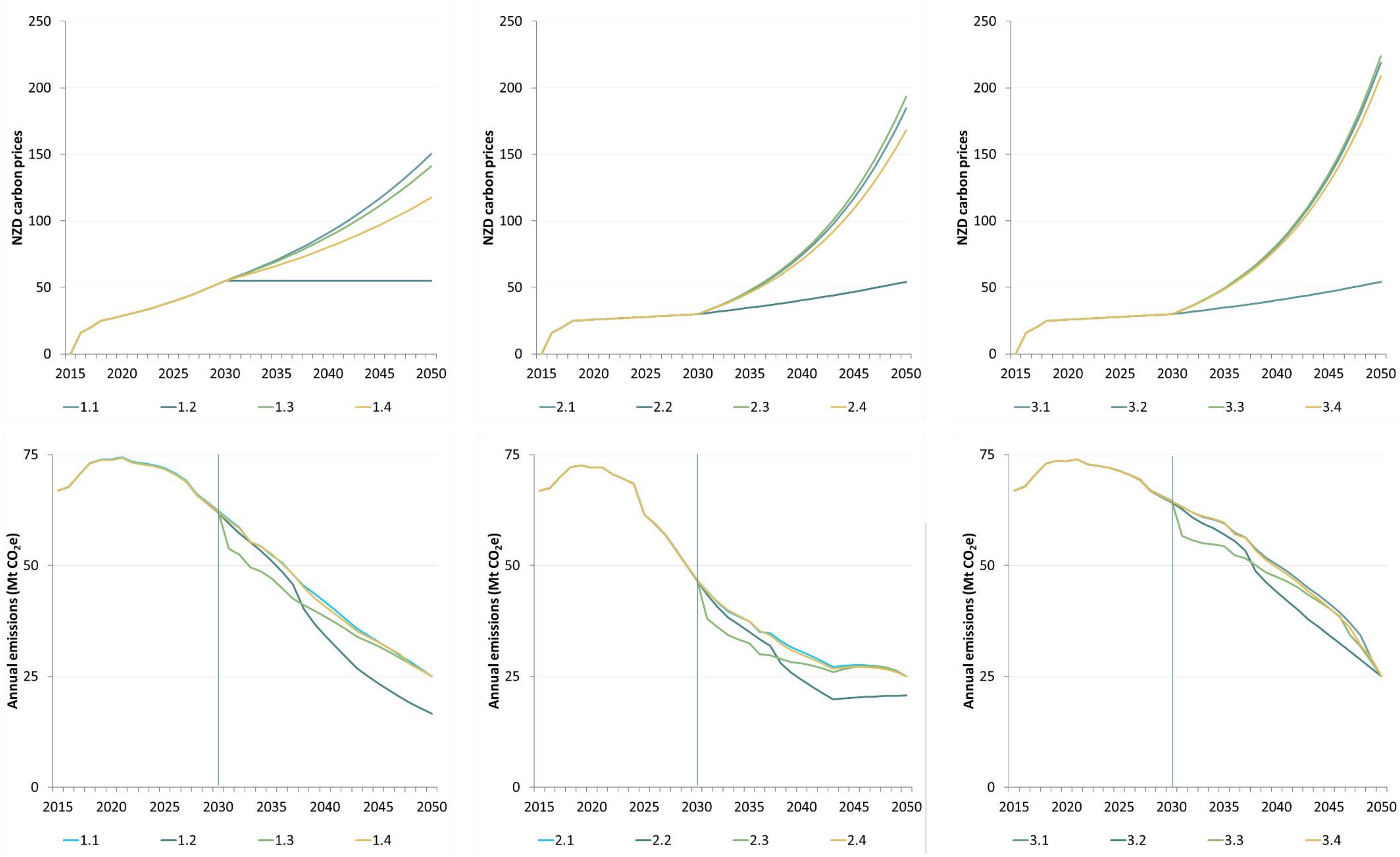
Figure 4. **Cumulative emissions over 2016–50 differ significantly between scenario variants**



Note: *GHG, greenhouse gas.*
Source: *Concept, Motu, Vivid Economics*

Emissions trajectories and associated carbon prices for each scenario variant are presented in Figure 5 below.

Figure 5. **Initial scenarios differ markedly regarding the 2050 emissions price needed to meet targets**



Source: *Concept, Motu, Vivid Economics*

3.1.2 Energy, industry and transport

The energy sector sees a major transformation under all scenarios and uncertainty variants. Reductions in the costs of renewables – particularly wind and utility-scale solar – see them expand rapidly to deliver almost all the additional generation required, as shown in Figure 6 below. This happens regardless of initial policy approach, with the closure of fossil capacity occurring in the longer term regardless of early action. Some scenarios see additional geothermal, but the growth is generally constrained due to the cost of greenhouse gas emissions from geothermal, and the assumption that wind and solar continue to decrease in cost much more rapidly than geothermal. Accordingly, electricity emissions reduce across all variants but remain around 2 $MtCO_2e$ in 2050 due to continued emissions from geothermal generation and gas peaking generators.

Electricity supply costs vary based on the scenario and uncertainty variant; however, the Disruptive decarbonisation scenarios are lowest-cost both in terms of cumulative costs over the period and cost per unit of electricity generation. This likely occurs due to the definition of these scenarios, which see the exogenously assumed closure of the aluminium and iron and steel industries in 2025 which in turn depresses overall electricity generation demand and investment in new generation thereafter, as well as assumed rapid reductions in the costs of renewables over the period to 2030. Across the variants the cost per unit of electricity in 2050 ranges between an 11 per cent cost reduction from 2015 levels to a 12 per cent increase.

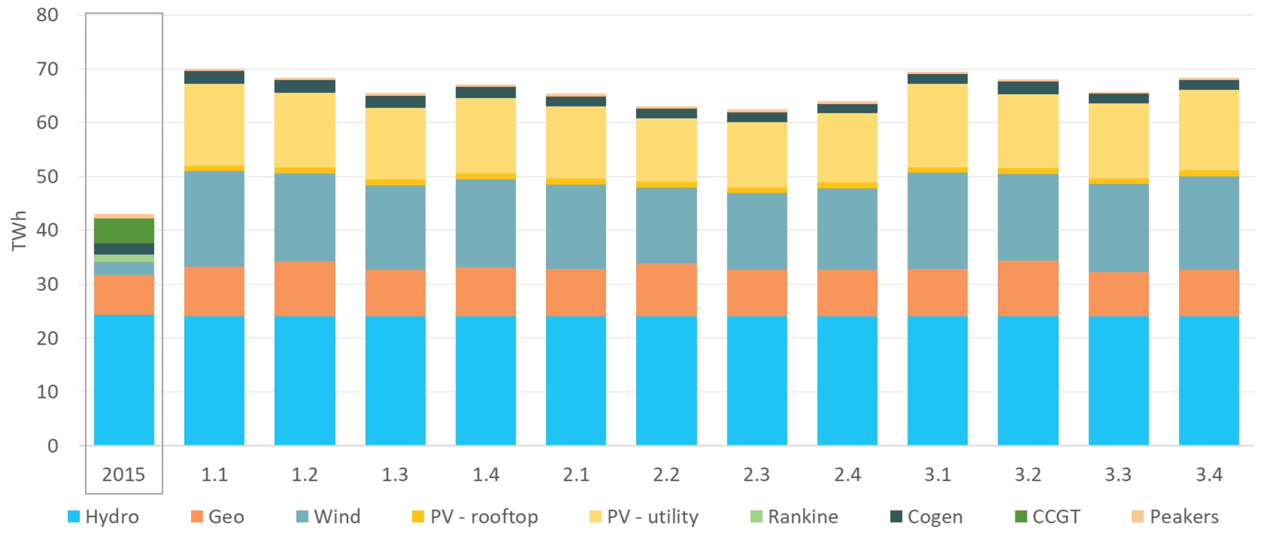
Emissions reductions in industry are driven by a combination of reduced process-heat emissions, industry closure and reduced refrigerant emissions. Emissions from industry's direct use of energy reduce significantly, particularly in higher-emissions price scenarios which enable a shift to lower-emissions energy sources including through electrification and increased use of biomass. Process-heat investments are capital-intensive and have long lifespans. Given this and the eventual need to decarbonise these sources in several scenarios, there may be a case for further policy actions to support movement to low-emissions sources of heat.

In the Disruptive decarbonisation scenario, aluminium and iron and steel smelters are assumed to close. In all other scenarios, however, aluminium continues to operate while iron and steel closes in only the higher-cost Stabilising decarbonisation scenarios. The closure of these industries sees a reduction in revenue earned by these industries of close to NZ$2 billion per annum.[6] Significant emissions reductions are also sourced from reduced emissions from refrigeration, as New Zealand implements its commitments made under the Montreal Protocol.

---

[6] Revenue is a poor proxy for economic cost since in the long run the capital is often reallocated to other productive uses.

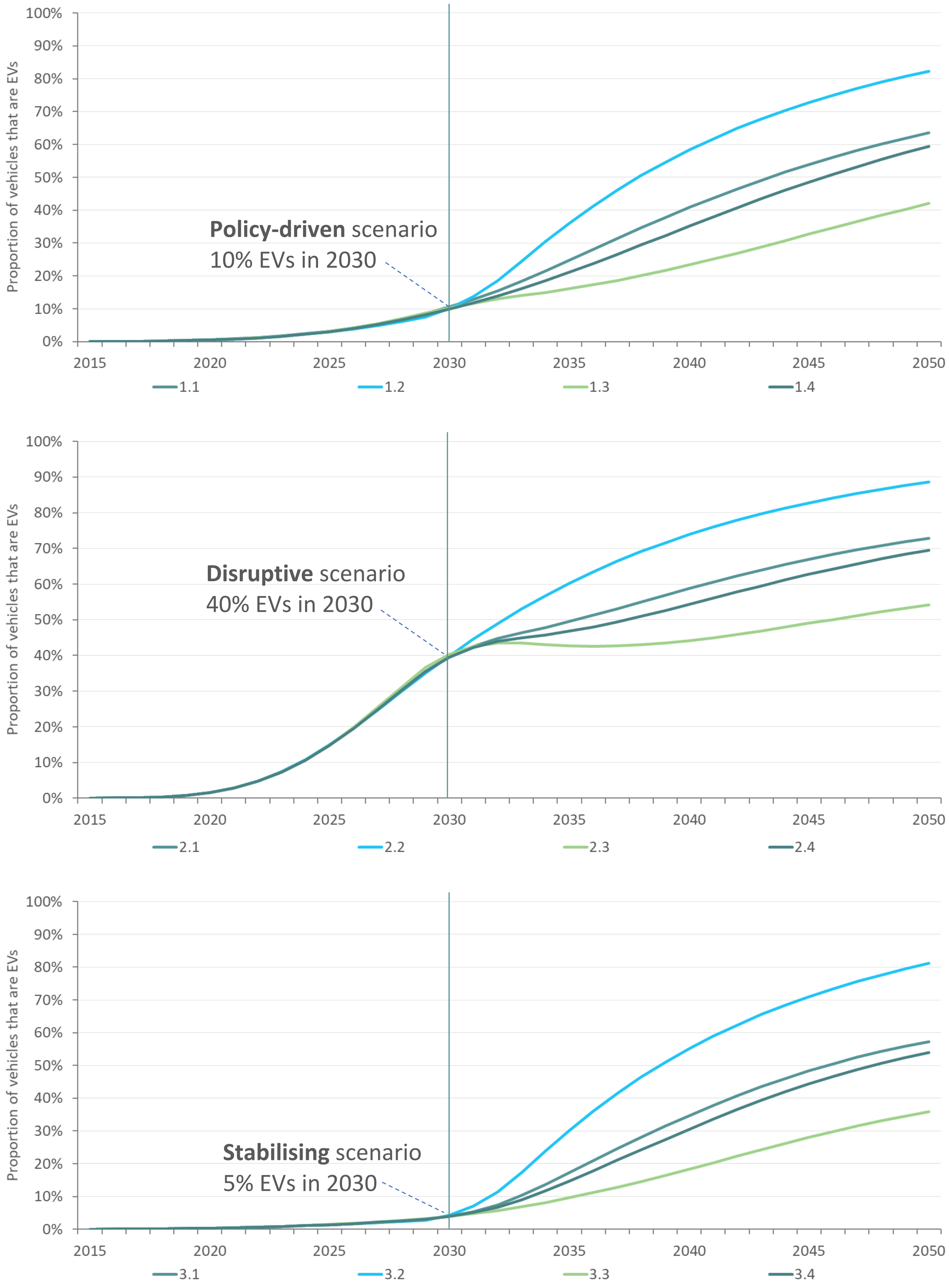
Figure 6. **Technological developments drive a near-total shift to renewable electricity**



Note: *PV, photovoltaics.*
Source: *Concept, Motu, Vivid Economics*

Mitigation in transport is largely determined by the expansion of EVs, with the initial scenario having a significant impact on EV uptake. EVs reach 5 per cent of the total vehicle fleet by 2030 in the Stabilising decarbonisation scenarios, 10 per cent in the Policy-driven scenarios, but over 40 per cent in the Disruptive decarbonisation scenarios, supporting large early emissions reductions. These early gains are reflected somewhat in later years with EV penetration reaching 50–90 per cent by 2050 in the Disruptive scenarios, but only 40–80 per cent in the Policy-driven scenarios, and 35–80 per cent in the Stabilising scenarios respectively. The penetration of EVs in the New Zealand market is shown in Figure 7 below. The ongoing impact of an early expansion in the EV fleet reflects the extended time periods for turning over vehicle stock. This means that initial slow rates of uptake may take an extended period to work their way out of the system. Scenarios do not differ substantively in terms of costs of purchasing and operating vehicles, or in externalities from the transport sector, with differences being greater between uncertainty variants rather than scenarios.

Figure 7. **Early expansion of EVs has a long-term impact on usage**



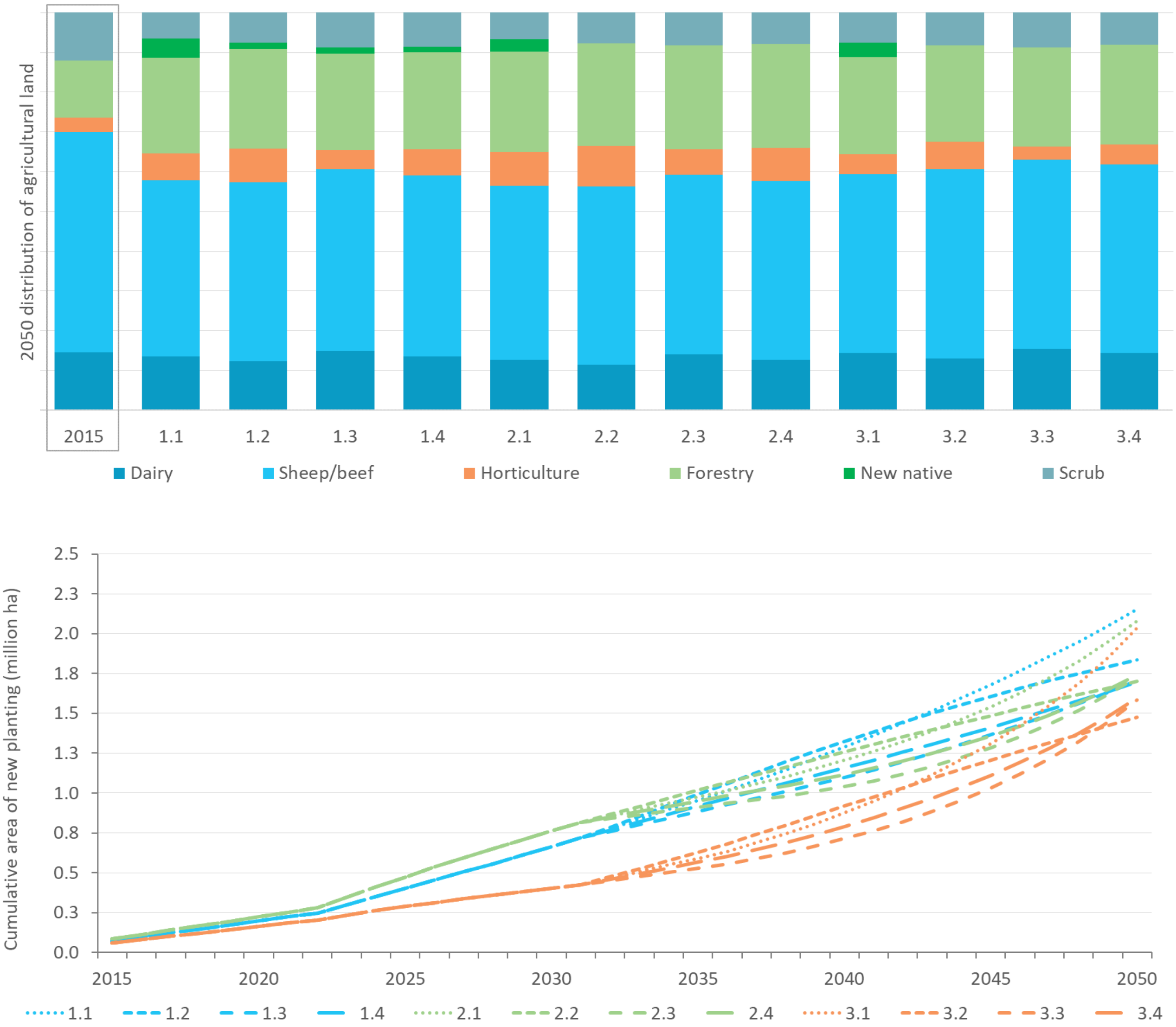
Source: *Concept, Motu, Vivid Economics*

3.1.3 Land sector

As in the interim modelling, these results suggest that, across all scenarios and uncertainty variants, clear shifts in land-use will be required to achieve New Zealand's targets. Central to this is a moderate reduction in land-use for pastoral agriculture which enables a relatively significant expansion in New Zealand's forestry industry.

The expansion of forestry and shifts in land-use patterns are detailed in Figure 8.

Figure 8. **Land-use patterns are mostly stable, but expansion of forestry is relatively significant**



Note: *LURNZ models from 2012 onwards, as such the new plantings series, start at a level above zero from 2015.*
Source: *Concept, Motu, Vivid Economics*

The reduction in pastoral agriculture is concentrated in sheep and beef production, which falls in all scenarios and variants, with dairy facing a mixed outlook. Between scenarios, pastoral agriculture is higher in the Stabilising decarbonisation scenario, which features both smaller reductions in land used for sheep and beef farming and relatively higher levels of land-use for dairy. This is associated with the overall lower level of expansion in horticulture and indigenous afforestation relative to other scenarios. The expansion of forestry and horticulture in the Disruptive decarbonisation scenarios results in the largest reductions in pastoral land-use, and subsequently the largest reduction in nitrogen pollution.

These scenarios suggest that overall levels of afforestation, both native and plantation, are within reasonable bands across scenarios, reaching 1.5–2.2 million hectares. The timing of this expansion differs, however, occurring much earlier in the Policy-driven and Disruptive decarbonisation scenarios relative to the Stabilising decarbonisation scenario. Between the Policy-driven and Disruptive decarbonisation scenarios the type of forestry also differs, with the assumed expansion of native forestry in the Policy-driven scenario meaning that it makes up a larger share of afforestation in 2050.

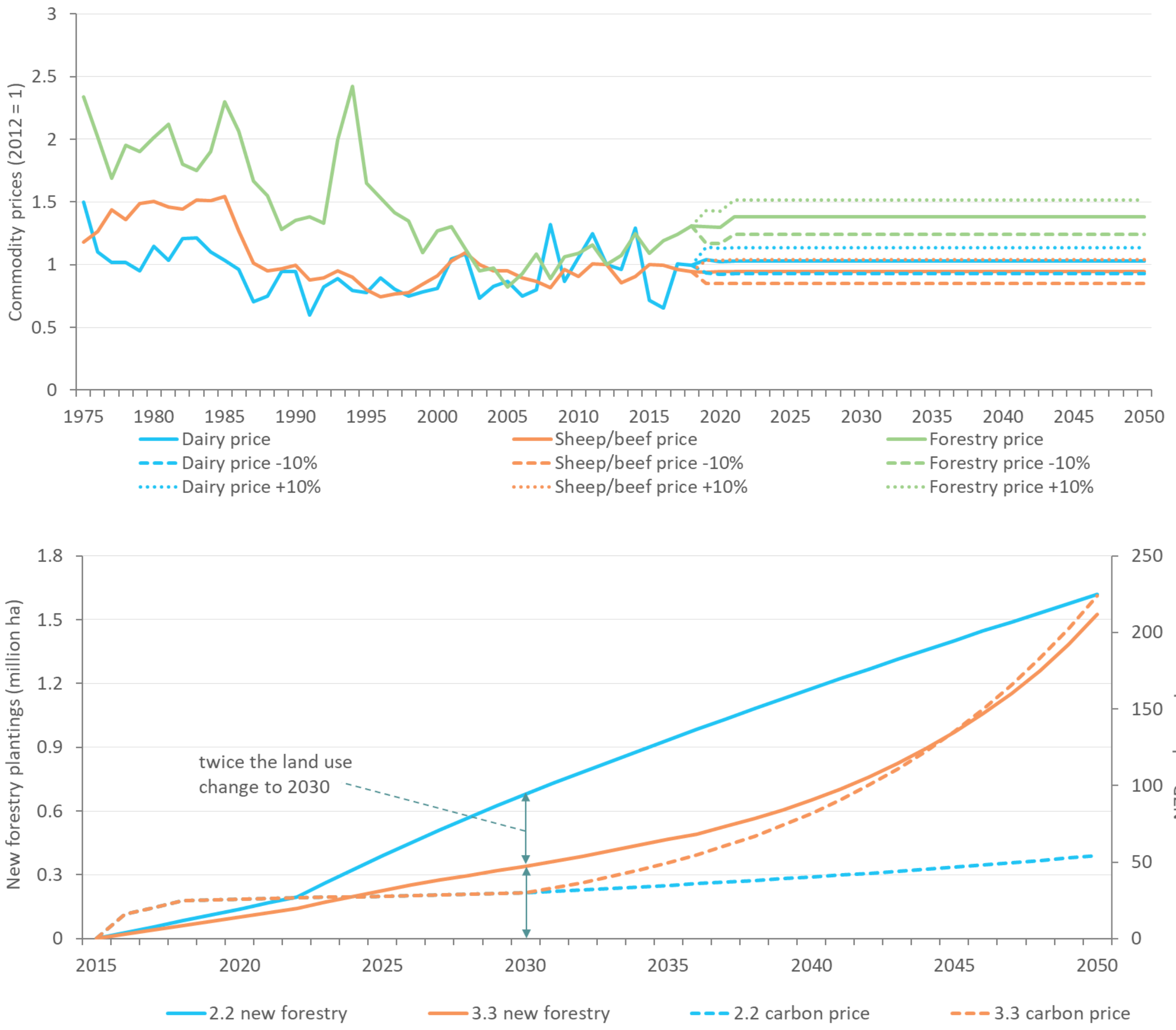
As plantation forests are harvested, almost all plantations established before 2030 do not provide further sequestration by 2050; in contrast, native afforestation that occurs before 2030 continues to provide sequestration well into the future. As harvested forestry provides only transient net sequestration, policymakers may wish to account for the timing of forestry expansion in their policy design. Further, the option to choose permanent plantation or native forestry rather than harvested plantation forestry will support sequestration over a longer timeframe.

There are trade-offs in the use of plantation or native forestry, with the former providing more rapid but transient sequestration, and the latter providing mitigation over the longer term and bringing greater potential co-benefits. Our modelling assumes that native afforestation occurs through government policy; however, this is likely to require additional government support on top of the rewards to foresters for sequestration if it is to form a major component of land-use change.

A major driver of the different planting rates between scenarios is the sensitivity of the land sector to relatively small shifts in commodity prices. For instance, the Disruptive decarbonisation scenario features pastoral agricultural commodity prices 10 per cent below baseline assumptions and forestry commodity prices 10 per cent above baseline, while the Stabilising decarbonisation scenario features the inverse, with higher agriculture prices and lower forest product prices.

These changes in long-run prices are relatively small compared with the historical shifts in prices that have occurred, as shown in Figure 9 below. Nonetheless these small changes in prices drive large changes in land-use decisions, with forestry expanding in the Disruptive decarbonisation scenario at about twice the rate as in the Stabilising decarbonisation scenario.

Figure 9. **A relatively small change in commodity prices can drive large changes in land-use**



Note: *The top panel presents an index of historical and assumed real commodity prices. To 2030, relative to scenario 3.3, scenario 2.2 has higher forestry and horticulture prices, lower prices for dairy and meat and lower free allocations to pastoral agriculture. Sensitivity analysis suggests that these commodity prices have by far the dominant effect. Post-2030, scenario 3.3 has a methanogen vaccine while 2.2 does not.*

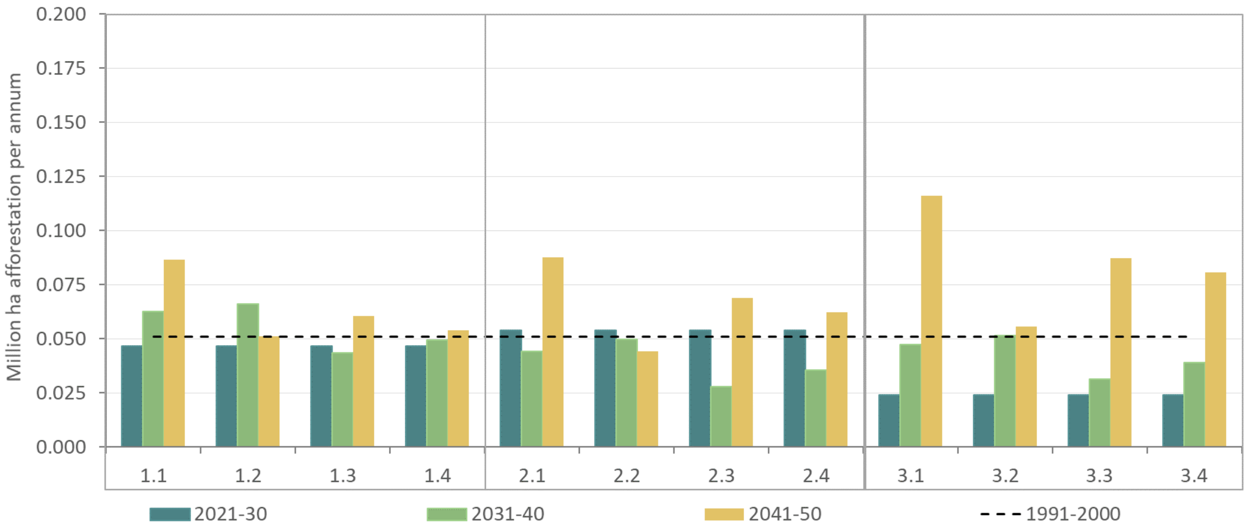
Source: *Concept, Motu, Vivid Economics, drawing on the MPI's 2017 Situation and Outlook for Primary Industries*

Modest land-use change to 2030 in the Stabilising decarbonisation scenario means that faster rates of land-use change are necessary to catch up with other scenarios. Accordingly, rates of afforestation far outstrip those in historical experience, at the extreme averaging up to 120,000 hectares per year in the 2040s – more than double the rate of afforestation in the 1990s (51,000 ha/year). While modelling suggests the total level of afforestation modelled is economically viable, afforestation at this rate could be challenging, particularly given much lower afforestation rates in earlier decades. On the other hand, a late ramp-up in land-use change would mean that significant amounts of sequestration can be expected in the 2060s and 2070s.

The Stabilising decarbonisation scenarios therefore entail more risk, as reaching New Zealand's 2050 target may not be possible at a reasonable cost unless planting rates far greater than those observed historically are achieved. Such a strategy is therefore likely to be less credible, and outcomes more sensitive to future developments.

In contrast, the Policy-driven and Disruptive decarbonisation scenarios see higher rates of forestry expansion to 2030 and require lower rates of planting in the period to 2050. This is shown in Figure 10 below.

Figure 10. **Some scenarios require rates of land-use change far exceeding recent experience**



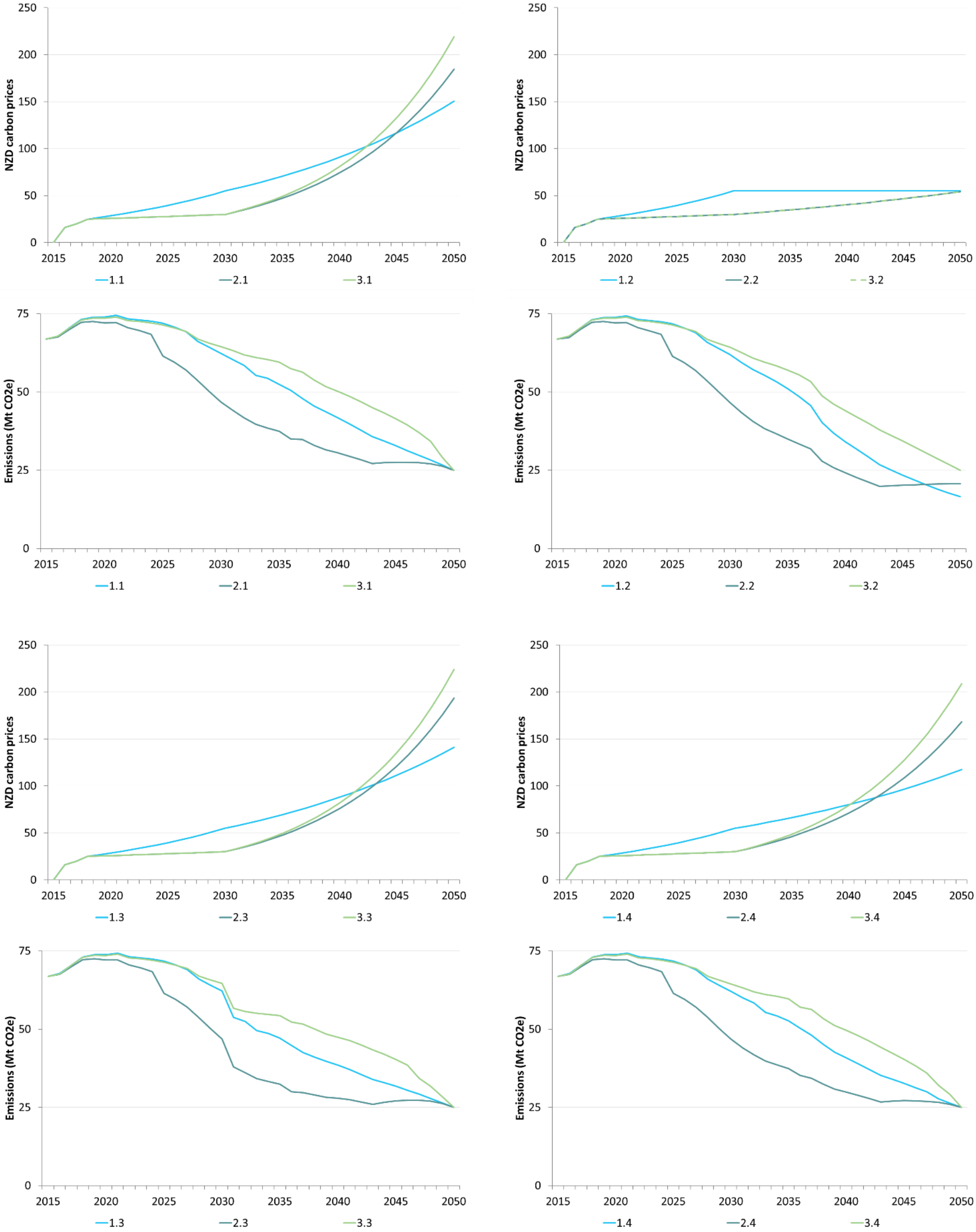
Source: *Concept, Motu, Vivid Economics*

3.2 Implications of uncertainties

The section above considers how outcomes differ by scenario; in this section we consider how outcomes differ by realised uncertainties. These key differences across uncertainty variants relate to required emissions prices, and the related distribution of sources of emissions reductions.

The key differential between uncertainty variants is the low emissions prices required to meet targets in the Innovation-disrupting-existing-industries variants. Across all three scenarios, when this variant is realised in the period beyond 2030, emissions reductions outperform the target even at very low emissions prices, not exceeding NZ$55 per tonne over the period to 2050. This price is substantially below the international emissions prices expected to be needed to achieve emissions reductions consistent with the objectives of the Paris Agreement. The price in this variant is also far below the price in all other variants, which reach between NZ$118 and NZ$224 per tonne in 2050, as shown in Figure 11.

Figure 11. **The Innovation-disrupting-existing-industries variant scenarios sees low emissions prices and outperforms emissions targets**



Source: *Concept, Motu, Vivid Economics*

Of these other variants, the Slow-international-action variant has the lowest prices. This is likely to be driven by a combination of variant-specific assumptions and the impact of higher relative emissions prices on competitiveness. It appears that the closure of, or reduced production from, iron and steel in this variant drives part of the differential, as is discussed in more detail below. In addition, compared with the Innovation-stabilising-existing-industries variant, the smaller price differential between agricultural and forestry products in the Slow-international-action variant reduces the relative marginal cost of abatement in the land section. Further, the assumed expansion of native forestry in the Moderate-technological-change variant likely reduces the land available for lower-cost mitigation from plantation forestry which pushes up its emissions price relative to the Slow-international-action variant.

The differences in emissions prices across uncertainty variants are reflected in the distribution of mitigation opportunities. The Innovation-disrupting-existing-industries variants feature far lower mitigation from manufacturing and construction, with reductions in emissions of only 20–30 per cent from 2015 levels by 2050. In contrast, other variants see emissions reductions of 40–70 per cent from this source. Higher relative emissions reductions occur in these variants because decarbonisation of process heat from fuel switching, particularly electrification, generally occurs at higher emissions prices.

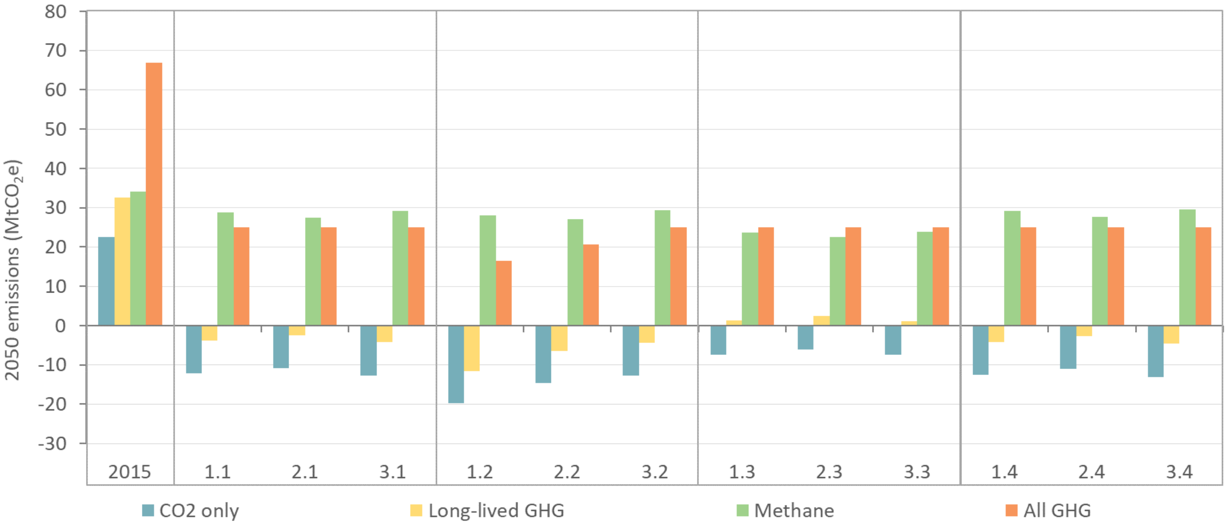
Emissions of long-lived greenhouse gases also differ by scenario. The New Zealand government is currently considering a range of 2050 targets for greenhouse gas emissions, including:

- **net zero carbon dioxide:** reducing net carbon dioxide emissions to zero by 2050
- **net zero long-lived gases:** reduce emissions of long-lived gases to net zero by 2050, while also stabilising emissions of short-lived gases
- **net zero emissions:** net zero emissions across all greenhouse gases

Figure 12 shows the 2050 emissions for each scenario and variant in these categorisations.

All scenario and uncertainty variants easily achieve the net zero carbon dioxide target, while all except the Innovation-stabilising-existing-industries variant achieve net zero long-lived gases. In this case, the reduction in methane emissions stemming from the post-2030 development of a methane vaccine means that methane emissions form a smaller share of total emissions and, as such, a smaller reduction in long-lived greenhouse gases is required.

Figure 12. **All variants achieve net zero carbon dioxide, and all but one net zero long-lived gases**



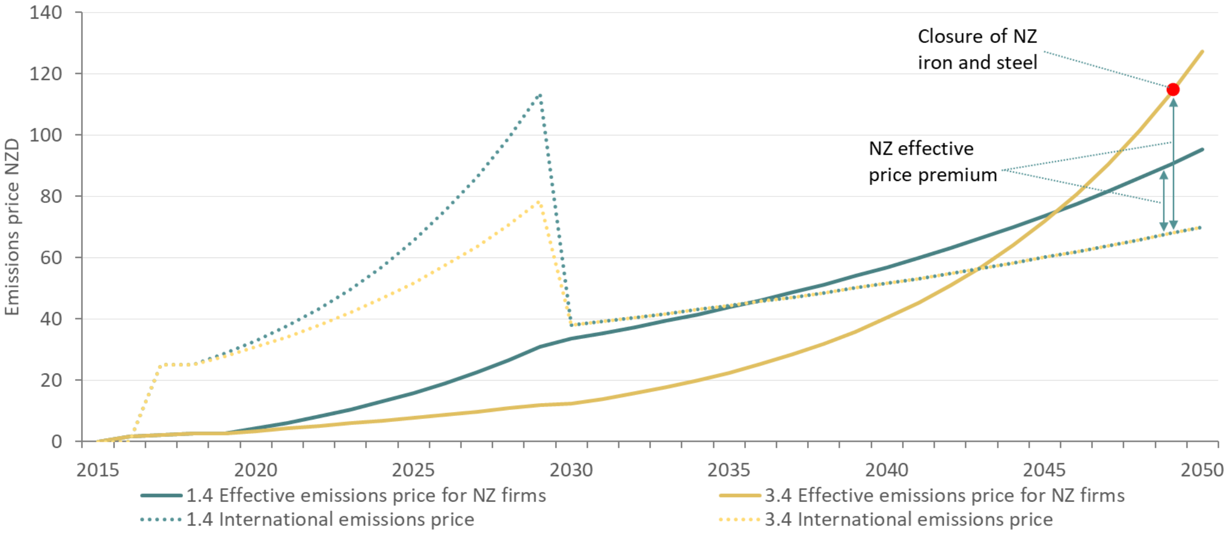
Note: *Short-lived emissions refer to methane; long-lived refers to all other emissions sources.*
Source: *Concept, Motu, Vivid Economics*

A salient risk facing countries developing climate policy is that other countries may not act at the same rate. The Slow-international-action variant seeks to reflect this eventuality, with lower international emissions prices potentially making New Zealand's emissions-intensive trade-exposed (EITE) firms less competitive, and relatively slow technological change increasing the potential costs of mitigation. Prior to 2030, all scenarios assume international action in line with the Paris Agreement and international emissions prices are significantly higher than those in New Zealand in this period.

In the Slow-international-action variant, however, international emissions prices fall rapidly in 2030 to simulate international climate action that is insufficient to achieve the objectives of the Paris Agreement. In response, we assume the New Zealand government reduces the rate of free allocations to emissions-intensive firms by 1 percentage point per year. In contrast, under the other variants, free allocations decline by either 3 or 5 percentage points per year and are fully removed prior to 2050. The Slow-international-action variant sees similar outcomes for production decisions across sectors as in other variants, and the New Zealand emissions prices required to meet targets are of a level similar to those required in other uncertainty variants.

There is some evidence that low global emissions prices in the Slow-international-action variant may have adverse impacts on New Zealand industry in the late 2040s. As the New Zealand emissions price increases rapidly to meet the 2050 target, even a slower rate of withdrawal of allocations sees an emissions price premium develop in New Zealand relative to the rest of the world, as shown in Figure 13 below. This contributes to the closure of New Zealand's iron and steel sector just before 2050 in the Innovation-stabilising-existing-industries scenario. Other sectors do not appear to be affected, with aluminium production continuing. This reflects the greater emissions intensity of iron and steel relative to aluminium (given the renewables electricitydominated energy input for aluminium, compared with the more fossil-intensive coal and gas inputs for iron and steel). Overall this suggests the need for policy flexibility to safeguard trade-exposed industries when global action is slow, and conversely to reduce allocations when global action is faster. This need not require less ambitious emissions targets but does require nuanced management, as outlined in the discussion of sensitivities in the following section.

Figure 13. **Higher effective emissions prices in the Slow-international-action variant may cause leakage**



Note: *Scenario variant 1.4 has a high International emissions price to 2030 which is at the upper end of the Paris-consistent range and then falls to be consistent with the Slow-international-action variant, which is below the Paris-consistent range. Scenario variant 3.4 has a medium international emissions price to 2030 which is towards the middle of the Paris-consistent range, before falling to the Slow-international-action variant price. Scenario variant 2.4 has been excluded as it does not add substantively to the comparison.*

Source: *Concept, Motu, Vivid Economics*

In many of the scenario variants, modelled New Zealand emissions prices are far below the assumed Paris-consistent emissions prices. This means that in scenarios where New Zealand's emissions prices are materially lower than international prices, New Zealand actors will not be investing in low-carbon technologies (such as electrifying process heat) which would be economically and environmentally justified on a global scale. The reverse is the case in scenarios where New Zealand emissions prices are materially higher than international prices; this would suggest that more overseas mitigation should be pursued.

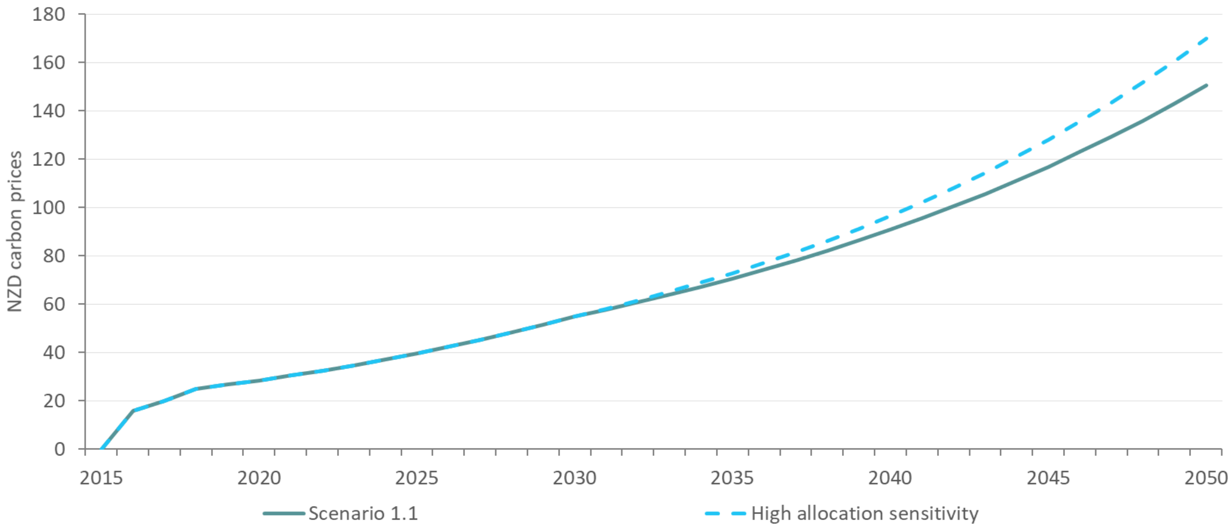
Other differences between uncertainty variants are largely unsurprising. The Innovation-disrupting-existing-industries variant delivers a much higher penetration of EVs, including significant decarbonisation from expansion into the heavy vehicle fleet. The expansion of EVs is reflected in higher electricity sector demand and higher aggregate network costs; however, technological developments also contribute to this variant, delivering the cheapest electricity per unit of generation. Similarly, the expansion of EVs reduces transport-related externalities, for instance reducing health costs by reducing particulate pollution. In the land sector, the Innovation-stabilising-existing-industry variants see substantially higher production of dairy and meat products. However, this variant also delivers little change in the level of nitrogen pollution, which declines in all other uncertainty variants.

3.3 Sensitivities

The discussion above has focused on how scenarios perform given uncertainty; this section builds on this discussion by considering the potential sensitivity of these results to different free allocation policies and population growth rates within a given scenario-variant combination.

Testing the sensitivity of free allocation: a slower rate of withdrawal of industry assistance to EITE firms has only modest effects. Under this sensitivity, we assume international action in line with the objectives of the Paris Agreement, but with assistance fully removed by the late 2040s, as compared with the late 2030s under scenario 1.1 which is used for this comparison. However, the higher relative rate of assistance has little impact on production choices and leads to an emissions price approximately $20 tCO$_2$e higher by 2050, as shown in Figure 14 below. This suggests that, should international action be slower than anticipated, there is scope to address risks of carbon leakage by slowing the withdrawal of free allocations. This reinforces our finding in the section above that risks of leakage can be managed by altering rates of industry assistance while having only a relatively small emissions-price impact.

Figure 14. **Higher rates of free allocation increase the required emissions price**

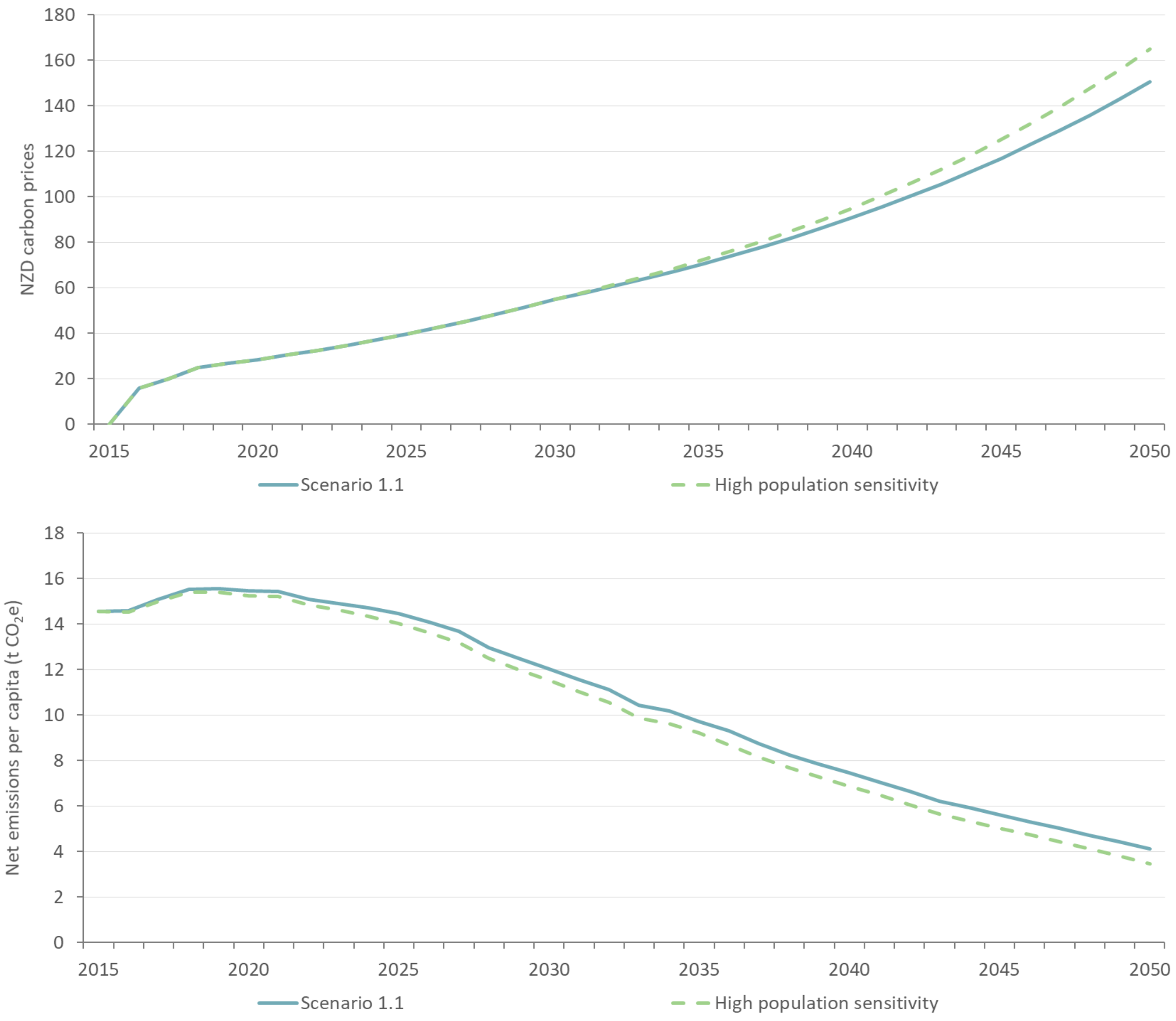


Source: *Concept, Motu, Vivid Economics*

Testing sensitivity to higher population growth: higher population growth also has only a modest effect on emissions prices. In this modelling run, population grows in line with Statistics New Zealand’s high population growth sensitivity, at about 1.3 per cent per year, compared with about 0.8 per cent per year in scenario 1.1. This higher growth rate increases emissions through two main channels – increased demand for transport and for residential and commercial energy.

The expansion of population means a higher emissions price is required to achieve the emissions target. However, this difference in price is relatively small, increasing 2050 prices by only NZ$14 tCO_2e, as shown in Figure 15 below. A major contributor to this outcome is the fact that, by 2050, a significant proportion of vehicles entering New Zealand are likely to be EVs. As net emissions fall, New Zealand's growing population is associated with lower net emissions per capita. They fall substantially from about 15 tCO_2e per capita in 2015 to around 4 tCO_2e per capita by 2050.

Figure 15. **Higher rates of population growth have a small impact on emissions and emissions prices**



Source: *Concept, Motu, Vivid Economics*

Table 4. **Key indicators: Uncertainty variants**

	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4
Overall												
Net emissions (MtCO_2e)												
2015 (est.)	66.9											
2050	25.0	16.6	25.0	25.0	25.0	20.7	25.0	25.0	25.0	25.0	25.0	25.0
2016–50	1,889	1,768	1,824	1,881	1,603	1,507	1,549	1,597	2,023	1,937	1,960	2,013
Gross emissions (MtCO_2e)												
2015 (est.)	80.2											
2050	55.3	53.7	55.4	56.4	49.0	48.9	48.7	50.4	53.6	55.8	52.8	54.5
2016–50	2,465	2,424	2,410	2,483	2,280	2,247	2,227	2,297	2,525	2,495	2,462	2,538
Emissions price (NZ$/t$CO_2$e)												
2050	150	55	141	118	185	54	193	168	219	54	224	209
Energy												
Wholesale energy + network costs (NZ$ billion)												
2015 (est.)	12.8											
2050	13.4	12.3	14.1	13.4	12.1	11.4	13.0	12.3	13.4	12.2	14.4	13.7
2016–50	485	465	497	487	450	442	461	454	486	467	504	496
Wholesale electricity costs (% change per MWh from 2015)												
2030	-3.4%	-3.5%	-3.4%	-3.5%	-8.8%	-9.1%	-8.5%	-8.8%	-6.4%	-6.7%	-6.4%	-6.4%
2050	-6.0%	-9.6%	-9.7%	-8.2%	-8.7%	-13.0%	-11.3%	-10.0%	-3.7%	-9.7%	-6.4%	-4.7%

	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4
Proportion renewables												
2015	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%
2050	96%	96%	96%	96%	96%	97%	96%	96%	97%	96%	97%	97%
Electricity sector emissions ($MtCO_2e$)												
2015	4.9											
2050	2.2	2.3	2.1	2.0	1.9	1.9	1.9	1.9	1.9	2.3	1.7	1.8
Transport												
Vehicle fuel, purchase and maintenance costs (NZ$ billion)												
2015 (est.)	16.5											
2050	14.9	21.1	18.2	18.7	13.9	16.1	17.4	18.5	17.3	23.5	15.0	14.8
2016–50	644	728	681	693	642	678	707	725	678	757	651	648
EV light vehicle share (%)												
2050	64%	82%	42%	59%	73%	89%	54%	69%	57%	81%	36%	54%
Externalities: construction, congestion and land (NZ$ billion)												
2015 (est.)	6.5											
2050	9.5	8.3	9.5	8.9	8.9	8.3	9.6	8.9	8.9	8.3	9.5	8.9
2016–50	287	269	286	278	277	268	285	277	278	270	287	278
Externalities: health (NZ$ billion)												
2015 (est.)	5.1											
2050	5.9	4.8	6.3	5.6	5.5	4.8	6.2	5.6	5.6	4.9	6.3	5.7
2016–50	204	187	207	198	192	182	201	193	199	189	209	200

	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4
Industry												
Revenue: Iron and Steel (NZ$ billion)												
2050	0.8	0.8	0.8	0.5[7]	0.0	0.0	0.0	0.0	0.2	0.8	0.0	0.0
2016–50	28.3	28.3	28.3	27.3	7.3	7.3	7.3	7.3	27.0	28.3	25.2	26.5
Revenue: Aluminium (NZ$ billion)												
2050	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0
2016–50	35.0	35.0	35.0	35.0	9.0	9.0	9.0	9.0	35.0	35.0	35.0	35.0
Agriculture and forestry												
Output: Dairy milk solids (% change from 2015)												
2030	7.2%	7.2%	7.2%	7.2%	2.0%	2.0%	2.0%	2.0%	11.0%	11.0%	11.0%	11.0%
2050	6.5%	-4.0%	17.6%	6.5%	0.4%	-10.0%	11.5%	0.4%	12.6%	2.4%	21.8%	12.6%
Output: Sheep/beef stock units (% change from 2015)												
2030	-5.9%	-5.9%	-5.9%	-5.9%	-7.8%	-7.8%	-7.8%	-7.8%	-3.3%	-3.3%	-3.3%	-3.3%
2050	-12.0%	-12.4%	-9.6%	-10.8%	-13.7%	-13.7%	-11.4%	-12.5%	-10.1%	-8.4%	-6.0%	-7.8%
Output: Forestry ha harvested (% change from 2015)												
2030	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%
2050	53.4%	53.4%	53.4%	53.4%	77.7%	77.7%	77.7%	77.7%	30.5%	30.5%	30.5%	30.5%

---

[7] This revenue figure reflects that iron and steel closes in the higher price run used in this interpolation but remains open in the lower price run.

	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4
Land area (million ha, 2050)[8]												
Dairy	2.0	1.8	2.2	2.0	1.8	1.7	2.0	1.8	2.1	1.9	2.2	2.1
Sheep/beef	6.4	6.5	6.6	6.6	6.4	6.5	6.5	6.5	6.5	6.9	6.9	6.9
Horticulture	1.0	1.2	0.7	1.0	1.2	1.5	0.9	1.2	0.7	1.0	0.5	0.7
Forestry	3.5	3.7	3.5	3.5	3.7	3.7	3.8	3.8	3.5	3.5	3.6	3.6
New native	0.7	0.2	0.2	0.2	0.4	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Scrub	0.9	1.1	1.3	1.2	1.0	1.1	1.2	1.2	1.1	1.2	1.3	1.2
Emissions from agricultural soils (% change from 2015)												
2030	-1%	-1%	-1%	-1%	-5%	-5%	-5%	-5%	2%	2%	2%	2%
2050	-8%	-14%	-1%	-8%	-12%	-18%	-5%	-12%	-4%	-9%	2%	-3%

Source: Concept, Motu, Vivid Economics

---

[8] 2015 land-use: dairy 2.1 million ha; sheep/beef 8.0 million ha; horticulture 0.5 million ha; forestry 2.1 million ha; scrub 1.7 million ha.

Technical appendix: modelling

This project uses 'structural' modelling of the New Zealand economy to project future possible emissions outcomes. The models are structural in that they break down the New Zealand economy into individual sectors, and then explicitly model the effect of key drivers of outcomes in those sectors. For example, the key drivers within the models include population growth, emissions prices, fuel prices, commodity prices, and technology costs. Linkages between sectors are incorporated through the outputs from one sector feeding into the inputs of another sector, both within and between models. For example, the outputs of LURNZ in terms of meat and dairy production feed into the ENZ module modelling industrial process heat which in turn feeds into the ENZ modules modelling electricity generation and gas production emissions.

LURNZ is a dynamic and spatially explicit partial equilibrium model of rural land use. It can simulate changes in dairy, sheep-beef, forestry and scrub in response to changes in economic incentives. In addition, it can spatially allocate exogenously determined changes in horticulture. LURNZ also includes functions to simulate land-use intensity and emissions (or sequestration) associated with these land uses. The foundation of LURNZ is provided by two econometrically estimated models that establish the relationship between observed drivers of land use and land-use outcomes. The first of these is a system of regression equations that estimate dynamic land-use responses to changes in economic drivers, such as commodity prices, at the national level. The second, spatial, component is a multinomial-choice model that relates land-use choices to various geophysical characteristics of the land, and to proxies for cost of market access, land tenure and yields. The dynamic and spatial components both have a strong empirical basis. This framework requires relatively few assumptions about farmers' objectives and decision processes: LURNZ results are largely driven by how land use has responded to its main drivers in the past. The model's underlying datasets and processes have been validated, and its results are consistent with data and trends at the national scale, including New Zealand's Greenhouse Gas Inventory.

ENZ is a series of inter-dependent modules or sub-models. The sub-models seek to identify the least-cost means of meeting demand for a service (for instance transport, process heat or electricity) given the underlying market drivers (such as population growth, emissions prices, fossil fuel prices and technology costs) and accounting for exogenously imposed policy actions (such as support for transport mode-shifting to public transport/cycling, or the forced closure of a fossil power station). Some sub-models are highly dynamic and model the key drivers of outcomes in significant detail. For example, the electricity sector modelling accounts for the intermittency in renewable generation (particularly in hydro and wind) and the transport sector modelling addresses the differences in outcomes between light and heavy fleet road transport. Conversely, some sub-models are relatively simple reflecting the relatively small share of emissions and/or significant inherent degrees of uncertainty, for example, modelling of waste sector emissions is based on simple marginal abatement cost (MAC) curves interacting with the emissions price.

These models attempt to simulate the outcomes in the real world given the underlying pathway drivers. In particular, they attempt to simulate the decisions that would be made by economic actors (businesses, farmers, households) seeking to maximise their benefit given the underlying price signals they face. For example, faced with high emissions prices, economic actors will tend to choose lower greenhouse-emitting options to provide an energy service (e.g. transport or process heat) and/or producers of a greenhouse-intensive product will be more likely to exit (e.g. closing a steel mill, or a farmer switching from dairy to horticulture).

The models apply a consistent set of macro drivers to all the sectors. i.e. a given pathway of emissions prices or oil prices will apply across the economy. Importantly, the structural modelling:

- takes account of the inter-linkages of the New Zealand economy. For example: projected dairy output driving the demand for process heat, which in turn will drive the demand for the fuels for such process heat (fossil, biomass and electricity), which in turn will drive outcomes in the electricity generation and gas production sectors.
- allows for non-linearities in drivers of outcomes (for instance, differences between baseload and peaking electricity generation requirements, or variations in the costs of available biomass, or variations in the different situations for industrial process heat users).
- allows for 'drilling-down' on projected outcomes to understand, what drives results, for instance, the relationships between future vehicle ownership, rates of EV uptake, mode shifting that drive projected land transport emissions, or competition between land use for forestry and agriculture.

That said, even with a disaggregated structural approach, it should be appreciated that:

- significant simplifications have had to be made in some sectors (such as waste);
- there are inherent uncertainties over factors which will significantly drive outcomes[9]; and
- there are material data gaps in some sectors (for instance the site-specific costs of existing, and potential future, industrial process heat plant).

In combination, this will give rise to a significant degree of uncertainty for the projections. However, even with these uncertainties, this modelling provides insights into the nature and scale of possible outcomes, and the types of policy choices which should help New Zealand move towards low greenhouse emissions in a way which maximises the environmental benefits but without causing excessive stress on the New Zealand economy.

This appendix addresses each of the individual sectors that have been modelled and:

- describes the key drivers of outcomes including demand, technology and fuel choices
- describes the approach taken to model these drivers and outcomes, including describing the parameters used for the different pathways explored

LURNZ

Land Use in Rural New Zealand (LURNZ) is national scale, spatial model designed to consider the implications of environmental policies on future land use, production and greenhouse gas emissions. It is a partial equilibrium model (Kerr et al. 2012), includes all private rural land in New Zealand, and can produce annual maps of land use at a 25 hectare resolution. LURNZ can be used

---

[9] For example, future technology costs (EVs, batteries, etc.) and oil prices will significantly drive future transport sector outcomes, but the future values for these factors are inherently unknowable

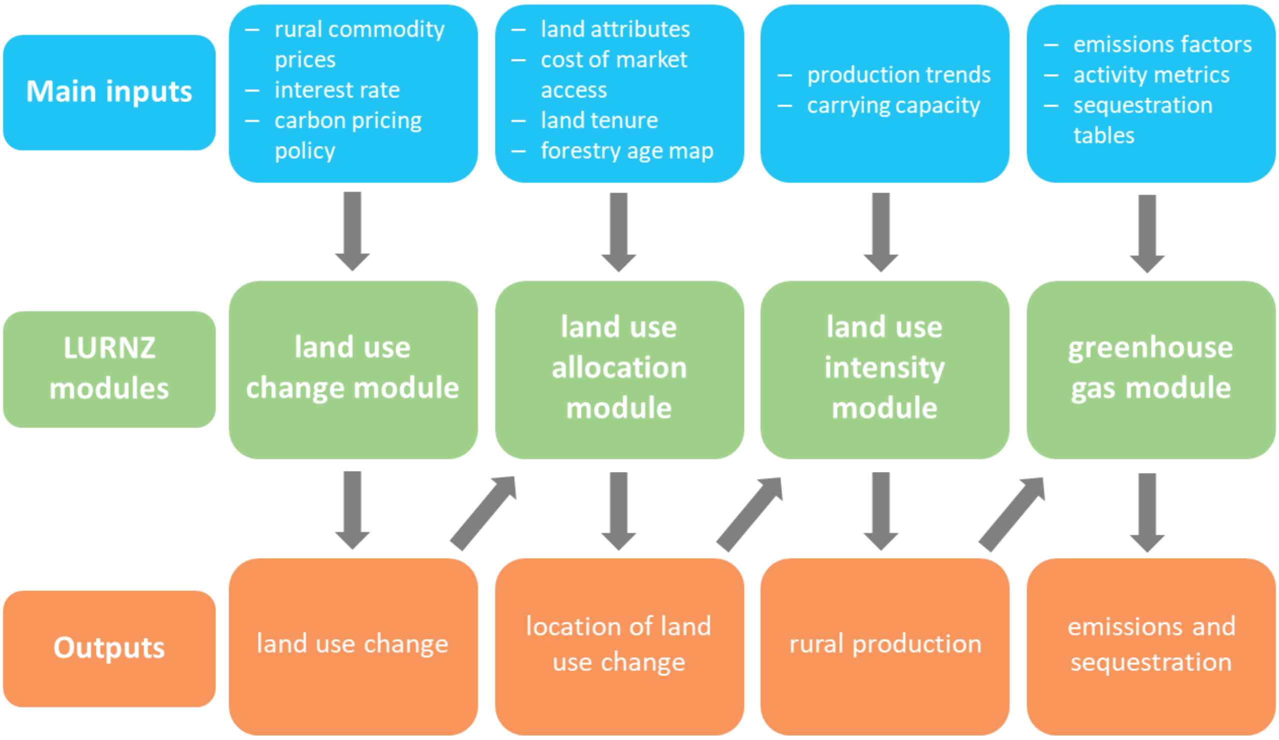
to simulate changes in dairy farming, sheep-beef farming, plantation forestry and unproductive scrub in response to changes in economic incentives. In addition, it can spatially allocate exogenously determined changes for horticulture.

The foundation of LURNZ is provided by econometrically estimated models that establish the relationship between observed drivers of land use and land-use outcomes. The revealed preference nature of these models enables us to make relatively few assumptions about farmers' objectives and decision processes: LURNZ results are largely driven by how land use has responded to its main drivers in the past.

Simulations in LURNZ are implemented by running its main modules in a pre-determined sequence (see Figure 16 below). The overall amount of land-use change is projected in the Land Use Change Module, while the spatial location of land-use change is simulated in the Land Use Allocation Module. LURNZ also includes functions to simulate rural production and emissions (or sequestration) conditional on the simulated land-use outcomes.

The model's underlying datasets and processes have been validated (Anastasiadis et al., 2014), and its results are consistent with data and trends at the national scale, including New Zealand's Greenhouse Gas Inventory (Timar and Kerr 2014).

Figure 16. **Schematic representation of the LURNZ model**



Main inputs

- rural commodity prices
- interest rate
- carbon pricing policy

- land attributes
- cost of market access
- land tenure
- forestry age map

- production trends
- carrying capacity

- emissions factors
- activity metrics
- sequestration tables

LURNZ modules

land use change module

land use allocation module

land use intensity module

greenhouse gas module

Outputs

land use change

location of land use change

rural production

emissions and sequestration

Source: *Concept, Motu, Vivid Economics*

Land Use Change Module

The Land Use Change Module is built around a system of regression equations that estimate dynamic land-use responses to changes in economic drivers, such as commodity prices, at the national level (Kerr and Olssen 2012, Kerr et al. 2012). The regression includes New Zealand's four major rural land uses: dairy farming, sheep-beef farming, plantation forestry and unproductive scrub. The coefficients of the model are estimated using historical commodity prices for dairy, sheep-beef and forestry.[10,11]

Modelling Emissions Pricing

The effect of an emissions trading environment (including emissions pricing and any free allocation) is modelled through adjustments to commodity prices received in each rural sector. We effectively assume that emissions costs affect farm decision-making in exactly the same way as commodity prices do through their effect on profits (Kerr et al. 2012). While this can be interpreted as the effect of the ETS, it could equally be interpreted as any type of policy that has the equivalent effect on the profit a land user earns - such as a subsidy, a tax, farm education and support, or efficiency gains resulting from R&D.

For dairy and sheep-beef, the effect of emissions prices on commodity prices is determined by calculating CO2-equivalent greenhouse gas emissions per unit of milk solids and meat produced. We also add a component to account for emissions from fertiliser use in each pastoral sector.

We model the carbon return to plantation forestry as the net present value of carbon credits from the first ten years of forest growth. Land managers' actual valuations of carbon return depend on idiosyncratic parameters that are difficult to model; these include parameters for risk aversion, as well as expectations of future carbon prices which may also depend heavily on expectations over future policy.

There is an important way in which using the net present value of carbon credits from the first ten years provides a conservative valuation: the carbon stock at ten years coincides with the minimum carbon stock held on land that is always replanted. Therefore, there is no liability risk from selling the carbon credits accumulated over the ten years after planting. The methods and intuition for calculating the carbon return to forestry are documented in more detail in Kerr et al. (2012).[12]

Policy changes with the expected introduction of averaging rules for forestry could see forest owners earning credits for the first 21 years of forest growth with no carbon price risk. Our methods potentially underestimate the carbon return to forestry under such a policy. However,

---

[10] Milk solid prices are reported in the Livestock Improvement Corporation's (LIC) Dairy Statistics reports; the sheep-beef price is a composite export unit value calculated from New Zealand's Overseas Merchandise Trade data set; forestry log prices are export unit values that match MPI's values for logs and poles for every year that they report data. For simulations of future periods, we use commodity price projections provided by MPI's Situational Outlook for New Zealand Agriculture and Forestry (SONZAF).

[11] We do not face the same challenges for estimating land-use response to economic returns as US-based studies do because commodity prices in New Zealand are credibly exogenous.

there are some factors that reduce the magnitude of this error: these include the discounting of returns accruing in the future and the continued existence of risks associated with policy change, as well as the possibility that under the new rules the liability for deforestation might exceed the amount of credits earned.

Finally, under the Emissions Trading Scheme, scrub land can also earn a return for its sequestration. There is no data on historical responses to scrub returns as scrub has never historically earned a monetary return. Scrub returns are therefore modelled through subtracting the potential carbon reward to scrub from the (already adjusted) commodity price projections of the other sectors (Kerr et al. 2012).

As with all econometric models, the projections of the model are most reliable when drivers of land-use change, the adjusted commodity prices, are within or near their historical ranges. In the output of the Land Use Change Module, dynamic projections from linearised over the first ten simulation years to focus on the long-run pattern of land-use change.

Land Use Allocation Module

The second, spatial, component of LURNZ is the Land Use Allocation Module. In this module, the national level changes in land use are allocated spatially across New Zealand on a 25-hectare resolution gridded map.

The module is parameterised using estimates from a multinomial logit discrete choice model that relates observed land-use choices to various geophysical characteristics of the land such as slope and Land Use Capability class, proxies for cost of market access like distance to towns and ports, and land tenure (Timar 2011). In addition to dairy, sheep-beef, forestry and scrub, this estimation also includes horticulture, enabling LURNZ to spatially model exogenous changes in this land use. The multinomial logit model predicts choice probabilities for each land use at each grid cell. LURNZ uses these probabilities as indicators of suitability. For any given land use, the grid cells with the greatest probability for that use are considered most suitable, while the grid cells with the lowest probability for that use are considered least suitable.

Given total annual changes in each land use and the estimated probabilities, an allocation algorithm assigns changes in land use spatially. The algorithm processes changes in horticulture land, followed by changes in dairy land, followed by changes in sheep-beef land, followed by changes in forestry land.

This order gives priority to land uses that are generally more profitable. Changes in scrub land occur as a consequence of changes in the other land uses. The rules within the algorithm are consistent with the intuition that if a land use is expanding, cells most suitable for the use will be converted first. The algorithm also minimizes the amount of land-use shuffling across cells; a detailed description of the allocation methodology can be found in Anastasiadis et al. (2014).[13]

---

[13] Compared to Anastasiadis et al. (2014), the rules governing transitions out of sheep-beef use in the allocation algorithm have been modified for this project. Previously, the cells with the lowest estimated probability for sheep-beef were abandoned first; now the sheep-beef cells with the highest estimated probability for scrub are abandoned first. This has improved the feasibility of projections, especially when exogenous constraints on other land uses are included in the simulation runs.

The conversion of plantation forestry to other uses is subject to two additional controls. First, LURNZ tracks the age of forests on each cell. Only those pixels that are identified as being of harvestable age (between 26 and 32 years) or as awaiting replanting (age zero) may change land use. Second, if forestry land is increasing, no forestry land may change to another use. On the other hand, if forestry land is decreasing then the amount of forestry land that changes to another use must not exceed the total decrease in forestry land.

Land Use Intensity and Greenhouse Gas Modules

Using the spatial projections of land use, LURNZ can simulate the associated spatial patterns of rural production and emissions (Timar, 2012). These are completed in the Land Use Intensity and Greenhouse Gas Modules, respectively.

In LURNZ, both intensity (production) and emissions are exogenously driven in the sense that they do not respond to changes in economic incentives such as emissions pricing. In other words, on-farm mitigation is not a response option within LURNZ, though it can be imposed exogenously.

To account for expected changes in production and greenhouse gas efficiency over time, LURNZ relies on extrapolating historical trends in the relevant variables. Projected changes in dairy farming involve the use of estimated trends in milk solid production per hectare by region. Estimated sheep-beef intensity varies by farm class and the carrying capacity of the land, but it is not modelled through time.

Projected emission factors for both dairy and sheep-beef farming have been supplied by the New Zealand Agricultural Greenhouse Gas Research Centre. The projections run through 2050, and they reflect increasing GHG efficiency over time in both sectors. These efficiency changes also affect returns to the various land uses. We account for their effect on land-use incentives by appropriately adjusting agricultural commodity prices over time.

To approximate production in plantation forestry, we calculate the area harvested in each year.[14]

Averaging and harvested wood products

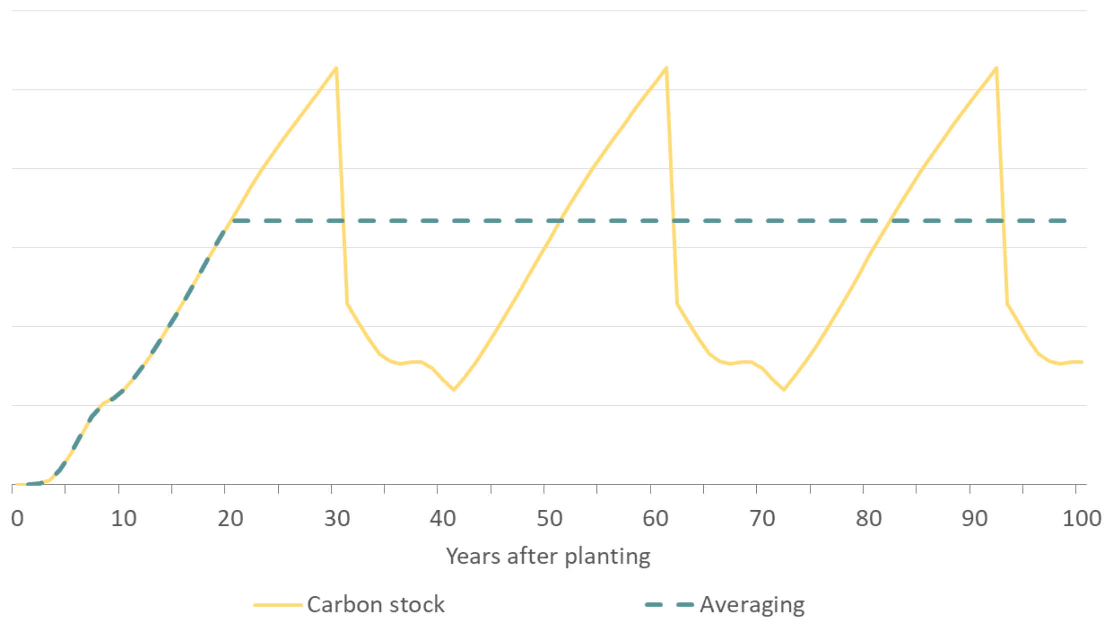
Forestry greenhouse gas modelling has been completely revised for this project to reflect the expected introduction of an averaging approach for the sector and accounting for emissions from harvested wood products.

Previously LURNZ results were based on UNFCCC reporting rules that lead to large fluctuations over time in net emissions. These fluctuations are driven by harvest patterns associated with the age class structure of New Zealand’s planted forestry estate. Under the revised rules, forests are credited only up to the point of the average carbon stock held in a permanent rotation, as illustrated in Figure 17 below.

---

[14] This is not a standard output of the Land Use Intensity Module, but it can be reconstructed from data generated in the background by forestry age tracking that runs during spatial allocation.

Figure 17. **Averaging reduces variability of emissions and sequestration over time**



Note: *Graph is indicative only, note sequestration counted under an averaging approach includes sequestration from increased carbon stock from harvested wood products which isn't included in carbon stock in the graph*

Based on a 28-year rotation and factoring in harvested wood products, we assume the average level of carbon stock is reached 21 years after planting. Based on the *pinus radiata* sequestration profile in the look-up tables underlying the National Inventory, this corresponds to an average annual accumulation of 31.83 tonnes CO2 per hectare over the first 21 years.

As the calculation is based on the net growth of forestry area, net forestry emissions are zero by design in the LURNZ base year (2012). However, forests planted in the 21 years before 2012 could also be contributing to removals but are not represented in the results thus far. We make an adjustment for this legacy sequestration by applying the revised accounting rules to net changes in plantation forestry are between 1991 and 2012.[15] Thereby we get an estimate of the contribution of past planting to current and future removals at the beginning of the simulation period. Legacy sequestration falls to zero over time, and from the perspective of achieving a 2050 target it is immaterial whether or not it is included. However, cumulative net emissions over the period leading up to 2050 are affected by its inclusion.

A few other points on the methodology of forestry modelling deserve some discussion. In LURNZ, we do not consider permanent carbon forests optimised for sequestration rather than harvest. Such forests accumulate carbon at a higher rate and over longer periods. At high carbon prices, some forestry is likely to stop harvesting and move to permanent carbon forestry. Our modelling does not capture this dynamic and could therefore underestimate sequestration (though the

---

[15] To keep things simple, we assume a linear growth in the carbon stock over the first 21 years when calculating legacy sequestration.

effects of carbon forestry would be more pronounced in the second half of the century which is beyond our simulation horizon). In this sense, LURNZ projections for the sector are conservative.[16]

On the other hand, the controls applied to forestry land-use changes in the allocation algorithm (described in the previous section) mean that LURNZ projects zero deforestation if overall forestry area increases. Emissions associated with deforestation are currently estimated at around 4Mt CO2 per year. As LURNZ cannot model this component, we expect to underestimate emissions from the sector by 4Mt under current conditions. This bias is expected to become smaller (or disappear entirely) at higher carbon prices, so it is not expected to have a major effect on scenario results.

Scrub

Net emissions from scrub land are relatively small and difficult to model accurately. To approximate it, we assume all scrub land is suitable for regenerating native forests. We apply the average rate of native sequestration over the first 50 years, 6.5 tonnes CO2/ha per year (Carver and Kerr 2017), to net changes in total scrub area relative to the base year. By treating removals and emissions from scrub symmetrically, this approach implicitly evaluates net emissions from scrub relatively to the base year.

Specific assumptions for this modelling exercise

This section expounds the implementation of different exogenous constraints and some modelling decisions relevant for this project.

Horticulture expansion

The Land Use Change Module excludes horticulture due to the difficulty of estimating price responses for the sector. This is in part due to the lack of a historical data series and in part due to the complexity of the sector: the horticulture category in LURNZ includes orchards, viticulture and cropping.

However, given exogenous scenarios on overall horticulture area change, the sector can be included at the spatial allocation stage in LURNZ. The rates of horticulture expansion we model under some of the variants are significantly higher than those observed in historical trends, but they are considered feasible by experts in horticulture.

Horticulture changes are dealt with on top of the allocation algorithm, so the most suitable land in any other use can be subject to transition into horticulture. An expansion of horticulture can therefore have flow-on effects affecting the area of all other land uses.[17]

---

[16] Recall from the discussion of the carbon price effect for forestry that the land-use response for forestry in LURNZ is also likely a conservative estimate.

[17] In some previous versions of LURNZ, an offsetting change was only applied to sheep-beef area. Total dairy area was therefore unaffected by horticulture change, though the spatial location of dairy could have been affected. Given the magnitude of horticulture expansion considered in this project, it is no longer considered appropriate to apply the area offset to sheep-beef only.

Constraint on dairy expansion
In all of the scenarios we constrain the expansion of dairy farming: no new land may be converted to dairying beyond 2025. This constraint reflects an anticipation of councils setting water quality limits in their regions.[18]

To implement the constraint, the land use changes established in the Land Use Change Module are overwritten before spatial allocation. To offset the change in dairy area, LURNZ finds the cells that would have transitioned to dairy farming in the absence of the constraint and keeps them in their previous land use. Therefore, the effect on overall land-use shares depends on the mix of land uses that would have changed into dairy without the constraint, which in turn depends on the magnitude and type of pre-constraint land-use change and the distribution of observed land attributes within each land use.

If the constraint on dairy expansion is combined with an exogenous growth in horticulture area, dairy area may actually decrease in the constrained period as horticulture is allowed to expand into existing dairy land, but new dairy cannot be established.

Native forest planting
Policy aspirations for native afforestation can be incorporated through the introduction of an exogenous parameter. This parameter controls the percentage of annual afforestation that goes to plantation forests versus permanent native forests. We assume that the policy intervention does not change the overall attractiveness of forestry land use, just the composition of planted species. The adjustment is implemented during post-processing of the standard LURNZ results using a non-spatial approach.

In the Policy Driven scenario and Moderate-technological change variant the parameter is set such that one third of the afforested area is planted with permanent native species.

The consequent decrease in exotic forest planting affects future harvested area once the forests reach harvestable age. The estimation of the effect on harvested area is performed while taking into account all LURNZ forestry parameters, including the ratio of harvested to harvestable area and the proportion of harvested forests in each age class.

The sequestration rate of native forest species is significantly lower than that of plantation forests. However, their effect is more enduring: removals associated with native afforestation continue throughout our simulation period (rather than stopping 21 years after planting as for harvested exotic forests). Because of the long time horizon required for a complete evaluation, the full effect of native planting on net emissions does not become apparent in our simulation period which ends in 2050.

---

[18] Without this constraint, dairy area in LURNZ simulations keeps growing even with emissions pricing. Econometrically, this happens because the estimated cross-price effect between sheep-beef price and dairy area outweighs the estimated own-price effect of dairy. Intuitively, emissions pricing has a larger effect on the viability of sheep-beef farming than it does on the viability of dairy farming.

Methane vaccine
In some variants we consider a technological breakthrough such as a methane vaccine that helps reduce emissions from livestock farming. It is assumed that the technology becomes available after 2030 and that it reduces methane emissions by 30% for dairy and by 20% for sheep-beef.

The technology affects both economic incentives for land-use change (so commodity prices are adjusted to reflect the change in emissions intensity) and greenhouse gas emissions from the pastoral sectors. The adjustments to both commodity prices and emissions are made with the assumption that the new technology affects only the livestock component of each sector’s emissions and that it is fully adopted in both sectors as soon as it becomes available.

ENZ

ENZ is a series of inter-dependent modules or sub-models. The sub-models seek to identify the least-cost means of meeting demand for a service (for instance transport, process heat or electricity) given the underlying market drivers (such as population growth, emissions prices, fossil fuel prices and technology costs) and accounting for exogenously imposed policy actions (such as support for transport mode-shifting to public transport/cycling, or the forced closure of a fossil power station). Some sub-models are highly dynamic and model the key drivers of outcomes in significant detail. For example: the electricity sector modelling accounts for the intermittency in renewable generation (particularly in hydro and wind) and the transport sector modelling addresses the differences in outcomes between light and heavy fleet road transport. Conversely, some sub-models are relatively simple reflecting the relatively small share of emissions and/or significant inherent degrees of uncertainty, for example, modelling of waste sector emissions is based on simple marginal abatement cost (MAC) curves interacting with the emissions price.

These key modules are outlined in Figure 18 below.

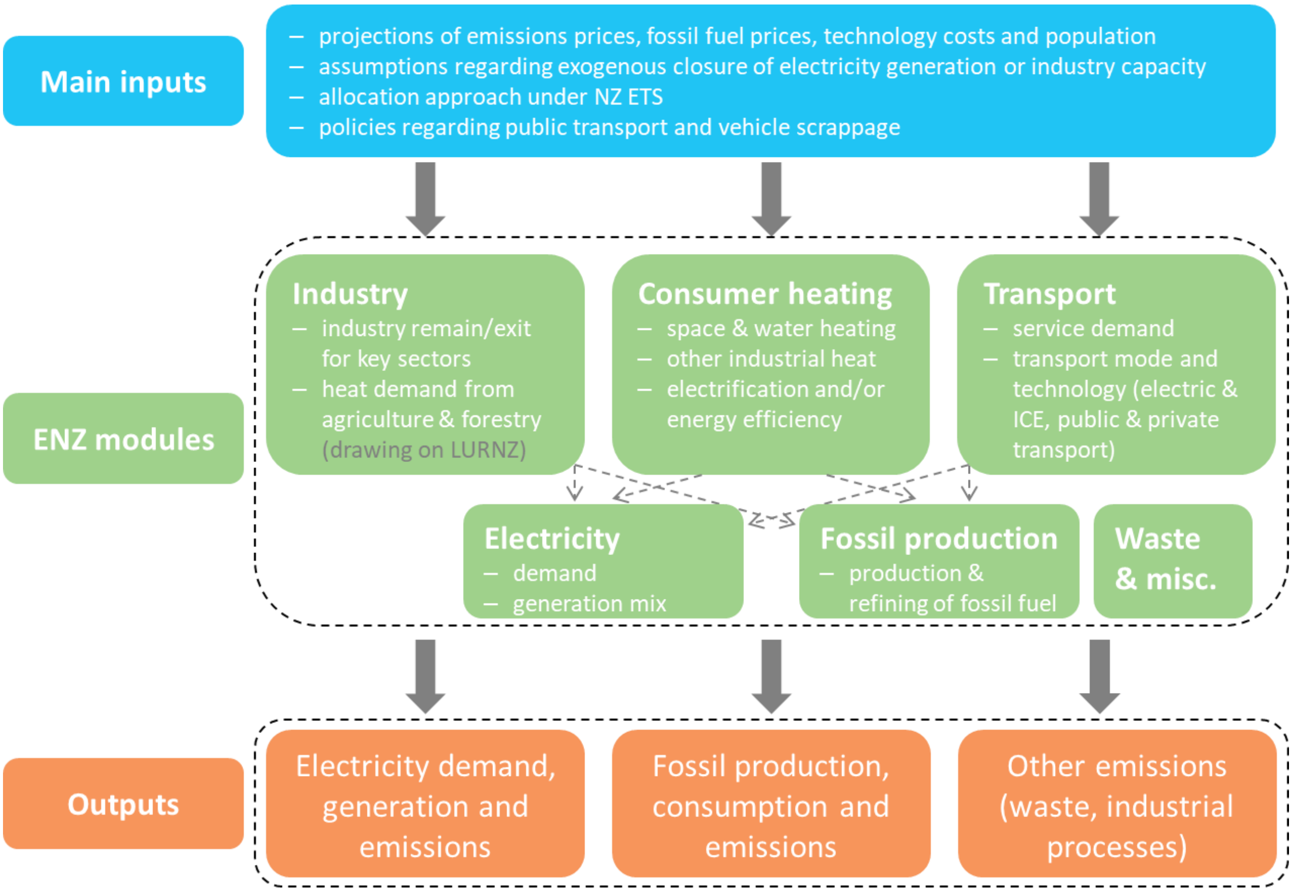
Industry

These are sectors whose emissions are very large, and whose output is significantly driven by international markets. Thus, either the New Zealand output is principally exported overseas (as is the case for dairy, meat, aluminium, and methanol), or some significant proportion of the New Zealand output is consumed within New Zealand but is competing with international imports of the commodity (as is the case for urea, and steel).

For these industries, future New Zealand production and emissions won’t just be a function of New Zealand policy, but also global developments, particularly the extent to which international producers of the commodity are exposed to emissions prices and technological developments.

The extent of international producers’ emissions price exposure, combined with the relative emissions-intensity of different global producers, will significantly determine the extent to which international prices and demand for the commodity will change. This will also be impacted by the extent to which there are substitutes for the commodity, and the relative emissions intensity and emissions price exposure of production of such substitutes.

Figure 18. **Schematic representation of the ENZ model**



Source: *Concept, Motu, Vivid Economics*

In turn, this will determine the extent to which New Zealand producers of the commodity will alter their output and associated emissions – either reducing production if such New Zealand producers are emissions-intensive relative to the rest of the world or keeping production stable or expanding production if New Zealand producers are relatively emissions-efficient.

ENZ makes two further key assumptions:

- The extent to which global demand for a product rises or falls with higher emissions prices
- The extent to which New Zealand producers are more carbon-intensive than the international producers against which they are competing

The modelling of these major industrial sectors varies between the following groups:

- Industrial commodities (aluminium, steel, methanol, urea, cement)
- Agricultural and forestry processing
- Other industrial emitters

Industrial commodities

This includes key sources of energy demand or emissions, specifically the aluminium, steel, methanol, urea and cement sectors. For these sectors the modelling simply determines whether

New Zealand production will continue or exit for the underlying pathway drivers – particularly scenarios around national and international emissions prices. There are no assumptions around possible new low-emissions technologies to produce steel or methanol, say, so emissions per tonne of output are projected to remain constant.

In terms of the modelling of whether a sector will exit due to increased emissions prices, current assumptions are that:

Aluminium

- World demand will rise with increased emissions prices (as aluminium substitutes for steel)
- New Zealand production is greenhouse-efficient given the high share of renewables
- high emissions prices are unlikely to result in the New Zealand aluminium smelter closing

Steel

- World demand will fall with increased emissions prices
- New Zealand production is not greenhouse efficient relative to international producers
- high emissions prices may result in New Zealand steel closing

Methanol

- World demand will remain static with increased emissions prices (based on the assumption that the demand for the products which use methanol – mainly as a feedstock for producing plastics and the like – will not significantly change for the period out to 2050)
- New Zealand production is relatively greenhouse efficient – relative to coal-based methanol production in China

Urea

- New Zealand demand for fertiliser will not fall below New Zealand production barring large shifts in dairy production – for instance due to the development of synthetic milk
- New Zealand production of urea is not the most greenhouse efficient, but has significant advantages from facing import parity prices, rather than export parity prices
- There are opportunities to improve the greenhouse efficiency of urea production by investing in the plant to improve its gas to urea conversion efficiency

Cement

- Given the costs of transporting cement over long distances, NZ-based production has relative comparative advantage to international producers, however it is unclear how emissions-intensive New Zealand producer is relative to competing international producers and whether demand for cement will significantly alter in a high emissions price world

There are significant inherent degrees of uncertainty over many of the above factors, plus significant data gaps in many areas (for instance, regarding where New Zealand is situated compared to competitors in terms of emissions-intensity) which will magnifies the uncertainty associated with these projections.

One of the most important factors is the extent to which a domestic New Zealand emissions price diverges from an international emissions price, and the extent to which emissions-intensive and trade-exposed New Zealand producers receive 'protection' from potential price imbalances. This is modelled through the operation of the industrial allocation mechanism. There is also the ability to apply an exogenous assumption for certain pathways that a sector will exit New Zealand at a future point in time. Such structural economic changes occur for a variety of reasons, however, appropriate policies may be required to mitigate the risk of emissions leakage. Emissions leakage can occur when production shifts from a producer facing an emissions price to a producer in another country that doesn't face the same emissions price and whose output is at least as polluting. The New Zealand ETS provides certain industries with free allocations to protect them from the risk of emissions leakage. This modelling assumes that these free allocations are gradually reduced as action to reduce emissions is accelerated globally in line with the Paris Agreement. The appropriate rate for the withdrawal of these allocations will depend in part on the degree of action occurring globally, particularly amongst New Zealand's trading partners.

Other significant factors affecting outcomes for these major industrial sectors include

- Electricity and gas transmission pricing. These will affect the competitiveness of New Zealand aluminium and steel and the economics of the electrification of industrial process heat. Current network pricing to consumers arguably does not reflect future economic costs – as prices are consumption-based but used for the recovery of sunk assets.
- Future gas exploration success in the Taranaki region. Future methanol output over the period of the projection is dependent on ongoing exploration, however we see no fundamental economic reason why this should not continue.
- Site specific factors for key sites such as decommissioning liabilities for aluminium and steel, benefits accruing to product specific attributes (e.g. the high purity of New Zealand Aluminium or the portfolio advantages New Zealand iron-sands based steel)

To keep the modelling tractable, these other factors were not explored. For methanol, it is assumed that additional reserves are progressively developed over time such that, on average, Methanex operates two of its three methanol trains – while noting that the 'lumpy' nature of reserves development means that this is likely to vary on a multi-year timescale.

Agricultural and forestry processing

For the food processing sector (predominantly dairy and meat processing), demand is a function of output from the LURNZ model. The ENZ model then models the extent to which this demand for industrial process heat is met by fossil (coal or gas) or low-carbon technologies – electricity or biomass. This is achieved through applying marginal abatement cost (MAC) curves whose values have been determined through stand-alone analyses of the economics of industrial process heat.

These stand-alone analyses indicate there is a very wide range of threshold emissions prices for fuel switching of industrial process heat, with site-specific factors significantly driving outcomes.

Key factors include:

- Delivered fossil fuel prices. In some cases, lignite and hard coal is understood to be delivered to processing plant gates at very low $/GJ prices. However, there is little publicly available data on such prices.
- The age of existing process-heat plant, with consequential significant variation in efficiency and non-fuel operating costs

This is also affected by the availability and cost of alternative fuel:

- Switching to biomass relies on the processing plant being located near forest operations with biomass resources of sufficient scale. While in some cases biomass may be available at low cost, other processing plants will face biomass costs that are significantly greater.
- The economics of electrification are likely to be affected by electricity transmission pricing. For instance, the proposed approach by the Electricity Authority in relation to recovery of the costs of recent major North Island transmission investments could support switching to electricity amongst South Island producers but not amongst North Island producers.
- There is some material uncertainty about the cost and efficiency of electric options to provide large-scale process heat, given that this is new technology.
- The required price to switch from gas to biomass or electricity, is much higher than the required price to switch from coal to biomass or electricity because of the higher emissions intensity of coal, the higher boiler operating costs of coal relative to gas and gas network largely sunk costs, whereas electricity demand growth could give rise to increased network costs which may affect the relative economics of gas to electricity fuel switching.
- The future demand for processing, for instance if there is a major shift away from dairy and/or meat, there will be much less demand for processing. If this demand uncertainty is significant, it will reduce the timeframe over which fuel-shifting investments are considered, making the required emissions price to make fuel switching cost-effective much greater. For example, a projected decline in output from the meat sector will make some least-cost options be to continue with a coal-fired boiler until the plant is closed due to reduced demand. However, if meat output were to remain constant, it would be least-cost to convert some existing coal-fired boilers to biomass or electricity.

The modelling for the emissions from the forestry processing sector is very limited, in large part because the process heat to undertake such processing is now largely provided by biomass – and thus low-emissions.

Fossil fuel combustion for low-temperature heat

The key decision-makers for this sector are consumers (households and businesses) deciding what appliance and fuel choice to make for space and water heating.

One of the key issues is that energy *use* is very capital intensive, with very low capacity factors for appliances. For instance, the average capacity factor of a residential space heater is about 4 per cent, and for a water heater it is about 8 per cent. This means that the capital component of costs can dominate the economics of options relative to fuel costs. This tends to result in options for fuel-switching largely only being feasible at times when new capital is anyway required: new build situations or replacing a worn-out appliance.

Network cost components are also significant drivers of the relative economics of gas versus electricity: given that the gas network is sunk with no need for capacity expansion the economic costs to New Zealand of gas transportation are very low. Conversely, in electricity, increased demand is likely to give rise to increased need to build more network capacity, the economic costs of electricity transportation to meet space and water heating demand can be much higher.

The effect of these factors means that required emissions price in order for switching away from gas to electricity could be several hundreds of dollars per tonne of CO_2. However, current electricity and gas prices to consumers generally do not reflect these underlying costs, for instance not signalling the peak-driven component of costs.

Other key relevant factors driving the relative carbon cost-effectiveness of different options to provide space and water heating include:

- Electricity generation to meet space heating demand is likely to be fossil-intensive, for instance infrequently-used gas generation in winter. Therefore, the carbon intensity of electric space heating is not too different to gas space heating.
- Non-price factors also play a very large role in consumer decision-making. For instance, cylinder-based water heating options increasing the risk of running out of hot water if multiple household members all want to take a shower/bath in quick succession, plus also taking up internal house space. Consumer perceptions (largely incorrect in the case of space heating) that gas heating is environmentally damaging relative to electricity heating.

The model projects future growth in demand for the heating 'service' driven by factors such as population and assumed rates of energy efficiency improvement, then uses a MAC curve approach to model the fuel switching outcomes from consumers. These MAC curves are based on stand-alone analyses and seek to capture the above factors in the fuel choice decisions of households and businesses. However, it should be noted there is significant uncertainty as to the levels for these MAC curves – due to uncertainty regarding the underlying economics, economically suboptimal consumer pricing, and as non-price factors play a significant role in consumer decision-making, particularly amongst residential consumers.

Transport

The transport model projects the demand for transport services, then projects the type of transport and associated fuel to meet such demand.

The demand projections are developed based on Ministry of Transport (MoT) historical transport statistics and the observed relationships between factors such as population and GDP and observed outcomes such as vehicle kilometres travelled (vkt) and freight travel.

The demand projections are split between:

- Land transport (which is further split between passenger, light commercial, heavy freight)
- Air; and
- Maritime.

Land transport
The land transport passenger demand projections are driven by factors such as population and vkt per head, both of which can be varied across pathways.

This demand for passenger transport services is further split between the main MoT reported statistics on travel purpose (for instance travel for work, education or social purposes) and the mode of travel (private vehicles, shared private vehicles, bus, train or forms of active transport). This latter aspect allows projections to be developed which examine pathway-based changes in the mode share for these different trips – such as an increase in public transport or cycling – with demand for light vehicle travel consequentially changing in both number of trips and distance.

Projections of population and GDP drive demand for commercial and freight travel. The outcome of these demand projections are projections of the demand for light vehicle, bus, and rail travel. The model then simulates the extent to which these demands are met by combustion engine technology, or electric vehicles[19].

Key drivers of these projections are pathway-based input assumptions regarding:

- technology costs (particularly battery technologies)
- oil prices
- emissions prices
- electricity prices, particularly the structure of consumer tariffs, and the extent to which they signal the variation in cost between peak and off-peak demand
- vehicle scrappage rates
- vehicle ownership rates, which are also driven by assumptions around passenger travel
- specific policy interventions

The modelling of EV adoption assumes an 's-curve'. This is observed to be a typical pattern of adoption of a new technology, reflecting the range of different types of:

- consumer situation, for instance demand for technology services – transport in the case of vehicles – and whether their existing appliance (or car) is old or new
- consumer preferences and attitudes, for instance early adopters preferences differ from those of late adopters, and the non-price aspects that drive consumer decisions can be a significant determinant of vehicle choice

A baseline rate of adoption was chosen based on the recent New Zealand MoT projection of rates of EV uptake in New Zealand based on current policy settings (particularly around emissions prices) and expectations of future EV cost reductions. This MoT projection results in 40 per cent of the light fleet being EVs in 2040, and over 90 per cent of vehicles entering the fleet being EVs at that time. This is consistent with projections in other countries.

Stand-alone calculations were made of the effect of different emissions prices, oil prices and EV capital costs on the lifetime economics of purchasing an EV, and what would be required for the relative economics of purchasing an EV versus an ICE in 2030 to be the same as that projected to

---

[19] In the case of rail, it is electric locomotives.

be the case in 2040 under the MoT projection. That is, to accelerate the rate of uptake such that achievement of over 90 per cent of vehicles entering the fleet would occur in 2030 rather than 2040. This is consistent with policies from the more ambitious countries seeking to achieve high EV uptake, such as the Netherlands which has proposed a ban on new ICEs in 2030, and Norway which is considering a ban as early as 2025.

This approach was then translated into a modelling framework where the s-curve rate of adoption results in more than 90 per cent of new-entry being 2040 for a combination values for Oil price, emissions price, EV capital costs, ICE efficiency improvements, and consumer electricity pricing structures. For a combination of higher values, it would result in an accelerated rate of uptake to get to more than 90 per cent of new-entry being EVs by 2030.

Stand-alone calculations were made as to the extent to which heavy freight vehicles would follow a lagged rate of s-curve uptake, due to the economics of heavy freight making EV economics more challenging. Although, simplified, this lagging behind light vehicle adoption is considered a reasonable way to estimate the rate of heavy freight uptake as battery technology, emissions prices etc. which affect the relative economics of EV vs ICE light vehicles will also affect such economics for heavy vehicles. This modelling is also consistent with hydrogen emerging as a technology for heavy freight vehicles, given that the hydrogen in New Zealand will also come from renewable electricity, and displace diesel in a similar way.

The model projects EV uptake for these different scenarios for the different types of travel (light passenger, light commercial, heavy freight, bus, rail), and the resultant costs (capital, non-fuel operating, and fuel) and fuel consumption (both electricity, and oil).

Air transport

Air transport projections are currently simplified within the model. Projections of the demand for air transport services are based on future population projections, factored by the price elasticity of demand for air travel (differentiating between business and non-business travel) driven by the underlying scenario for oil and emissions prices.

There is no new aviation technology modelled (such as battery or biofuel powered planes) as these are unlikely to be uneconomic for mass air travel before 2050, but the model does assume continued steady improvements in the fuel efficiency of aviation.

Maritime transport

There is no modelling of material changes to coastal shipping (including ferries) as this is currently a relative small proportion of New Zealand’s emissions, and battery and biofuel-powered ships are considered to face similar economic challenges to battery and biofuel-powered planes over the next few decades.

International transport

The transport model captures international aviation and marine transport and applies very simple projections. However, given that this is not included within the scope of this exercise, no effort has been made to consider these sources of emissions in any detail.

Electricity

The electricity sector model identifies the cheapest way to satisfy future electricity demand each year from 2017 through to 2050. The model has a demand module, and a generation module.

Electricity demand projections

The demand module splits demand between several key types of demand:

- the Tiwai aluminium smelter
- other large industrial consumers who are ‘directly-connected’ to the transmission network
- other industrial consumers
- commercial consumers
- residential consumers

This disaggregation recognises that the future drivers of outcomes are different between such demand types (for instance population growth is a key driver of future residential demand, but is not a relevant consideration for the Tiwai smelter), plus the within-year and within-day shape of demand is very different for these different sectors.

The demand module projects demand for these different sectors given the underlying pathway variables. Some of these demand projections are from within the electricity model, whereas other are driven by outputs from other ENZ models, in particular:

- electric vehicle demand from the transport model
- electrification of industrial process heat, from the major industry model
- electrification of fossil-based space and water heating from the consumer heating model

In addition, the model separately projects ‘negative’ demand from uptake of residential solar PV, plus separately projects the uptake of consumer batteries.

As noted above, all these different types of demand have different modelled ‘shapes’ in terms of within-day and within-year patterns of demand, plus the extent to which there can be extremes in demand which driven peaks on the system. These factors are critical to capture as the variability in demand significantly drives the need for low capacity factor generation and the extent of network assets required to meet system demand peaks. ENZ can model the ‘sculpting’ of demand from storage demand technologies such as EVs, and consumer batteries, based on the assumptions regarding consumer electricity price signals.

Electricity generation projections

The generation module determines for each year, the least-cost options for generation build, retirement and operation given projected demand and the pathway assumptions regarding fuel prices, emissions prices, and generation technology costs, emissions, and efficiencies.

This modelling addresses the following key ‘physical’ drivers of outcomes for New Zealand’s generation system:

- The characteristics of New Zealand’s hydro stations. In particular, the extent to which hydro schemes can store and release water given physical limitations including the extent

of storage, patterns of inflows, and the need to maintain minimum river flows, which determines the extent to which it could be ‘dry’ or ‘wet’ at different times of year
- The variability of wind power, and the correlation between variability of hydro inflows
- The shape and variability of demand

These factors interact in complex ways and give rise to the need for some generation to operate at lower capacity factors. These lower capacity-factor requirements are to provide:
- Hydro-firming – that is to increase or decrease generation in response to hydro inflows being lower or higher than average;
- Seasonal generation – that is to meet increased demand for electricity for heating in winter
- Peaking generation – that is to provide sufficient firm generation at times of extreme peak ‘residual’ demand – i.e. the combination of actual demand less the contribution from variable renewable sources of generation (e.g. wind, solar, and run-of-river20 hydro)

Hydro schemes are particularly complex in the above context. Some hydro schemes with significant storage are important contributors to meeting the demand for seasonal and peaking generation, whereas others with little storage can exacerbate the problem of a peak *residual* demand and make no contribution to meeting seasonal requirements. Plus, by definition, all hydro schemes are causing the need for hydro-firming generation.

ENZ projects the requirements for these different forms of low-capacity factor generation and determines the least-cost forms of generation to provide such requirements given the costs and controllability of different types of generation.

Importantly, some types of generation can contribute to meeting more than one requirement. Further, the *chronology* of these patterns of scarcity and surplus is critically important to determine the relative economics of different low-capacity factor generation options. In this respect, the pattern of New Zealand’s scarcity/surplus due to hydro variability is rare, and gives rise to the need for a system that can ‘swing’ very large quantities of energy over a 3-4 month period, but with a periodicity of being called upon measured in the 1-in-5 to 1-in-10 year timescale. This has significant implications for the type of generation and fuel supply that can meet this requirement.

Implications

Options for low-capacity factor generation

Lower-carbon options to meet dry-year, seasonal and peaking requirements include:
- Batteries (stand-alone or in EVs) – although these are only economic to meet peak requirements, but are uneconomic to meet seasonal and dry year requirements
- ‘Over-building’ renewables and using spill as flexibility ‘resource’
- Using demand response, although this is not an option for seasonal requirements as, by definition, it is causing the demand for low-capacity factor generation. Similarly, weather-

---

[20] Run-of-river hydro relates to hydro schemes which have little or no storage. The definition of ‘run-of-river’ can vary according to the scheme and context. For example, there are some schemes which have several weeks’ worth of storage capacity and can thus be considered ‘firm’ in the context of providing short-term peaking generation, but are of no assistance (and thus effectively ‘run-of-river’) in the context of providing seasonal generation.

driven demand extremes significantly contribute to the need for peaking generation. In general, demand response only starts to become economic for very infrequent requirements (that is less than 1 per cent of time)

Fossil options are relatively cheap due to relatively low capital intensity of fossil generation (particularly existing fossil stations), reflecting that it is expensive to build a wind farm that is infrequently utilised.

The deliverability of the fuel to meet dry-year requirements is also a key driver of the relative economics of gas and coal. Future methanol demand may have an impact on the economics of switching away from coal to gas-fired generation to provide hydro dry-year firming: diverting gas from methanol production to electricity generation in dry years can be cheaper than swinging gas production or gas storage – thereby lowering the required emissions price to use this as a means of dry-year cover, rather than coal-fired generation. However, if methanol production has ceased in NZ, this dry-year fuel would not be available.

Which type of renewables are likely to be least cost

This modelling suggests that rooftop solar is likely to be more expensive than wind and geothermal at providing renewable generation.

Geothermal is itself a source of greenhouse emissions. Therefore, in futures of high emissions price, relative to wind, the benefits of ‘firmness’ are outweighed by the high CO_2 costs. Further, wind costs are projected to decline at a much greater rate than geothermal costs. This means most demand growth and investment being met by new wind generation in the early years of the projections. However, at higher rates of wind penetration, the variability of wind starts to affect its economics relative to wind and geothermal, and some geothermal is developed. Likewise, once utility solar starts to become economic there is a period of development until the proportion of solar on the system starts to become material, which affects the economics of additional solar.

Once the points of relatively high penetrations of wind and solar are reached, future renewable development tends to be balanced across the different renewable technologies. The effect of ongoing technology cost reductions for wind and solar, balanced by the negative effect of variability at high penetration levels of such technologies, results in wholesale prices remaining largely steady in real terms, with some modest reduction potentially.

Other sectors

Oil and gas production and refining.

The emissions from these sectors are modelled as moving proportionately with New Zealand oil and gas production, which is a function of the detailed modelling of future oil and gas demand for all the above sectors.

Other liquid-fuelled motors

A significant source of emissions are liquid-fuelled motors which aren’t used for transport. These include farm machinery (such as tractors) and stationery motors used for commercial or industrial processes. The ENZ modelling has stripped-out this demand from the broader category of emissions from the reported non-transport emissions from the agricultural, commercial and industrial sectors. It has then assumed that the opportunities to move to electric motors are likely to be similar to those for the move to EVs for heavy freight, and therefore applies the same proportional move to electrification.

IPPU Emissions from refrigeration

This assumes emissions fall in-line with New Zealand's commitments under the Kigali agreement, with modelling allowing for faster rates of reduction proportional to International CO_2 prices being above threshold levels.

Waste

This is endogenously modelled through a very simple MAC curve-type approach.

References

Anastasiadis, Simon, Suzi Kerr, Wei Zhang, Corey Allan, and William Power. 2014. "Land Use in Rural New Zealand: Spatial Land Use, Land-Use Change, and Model Validation." *Motu Working Paper* 14–07. Wellington, New Zealand: Motu Economic and Public Policy Research.

Carver, Thomas and Suzi Kerr. 2017. "Facilitating Carbon Offsets from Native Forests." *Motu Working Paper* 17–01. Wellington, New Zealand: Motu Economic and Public Policy Research.

Kerr, Suzi, Simon Anastasiadis, Alex Olssen, William Power, Levente Timar and Wei Zhang. 2012. "Spatial and Temporal Responses to an Emissions Trading Scheme Covering Agriculture and Forestry: Simulation Results from New Zealand." *Forests*, 3(4):1133–1156.

Kerr, Suzi, and Alex Olssen. 2012. "Gradual Land-use Change in New Zealand: Results from a Dynamic Econometric Model", *Motu Working Paper* 12-06, Motu Economic and Public Policy Research, Wellington.

Timar, Levente. 2011. "Rural Land Use and Land Tenure in New Zealand," *Motu Working Paper* 11-13, Motu Economic and Public Policy Research, Wellington.

Timar, Levente and Suzi Kerr. 2014. "Land-use Intensity and Greenhouse Gas Emissions in the LURNZ Model." *Motu Working Paper* 14-03, Motu Economic and Public Policy Research, Wellington.