Modelling the transition to a lower net emissions New Zealand

Interim results

April 2018

:vivideconomics

concept

Motu

Motu Economic and Public Policy Research

Contents

List of tables

List of figures

1. Overview

In the coming years, a range of choices will be made by New Zealand's government, businesses and society that will influence the structure of the economy and the cost of reducing greenhouse gas emissions. The broad purpose of the Productivity Commission's inquiry is to identify the actions New Zealand might take to reduce its emissions given the range of choices in its control, recognising that some of the factors that will influence the desirability of those choices are outside of its control. The approach taken in our modelling seeks to set out the impacts of this decision making under uncertainty by considering how different decisions impact outcomes of interest, such as economic activity and greenhouse gas emissions, under uncertain future states of the world.

This note provides an interim update on this modelling work. It sets out three pathways, comprising different technological developments and matching policy and investment strategies that may be utilised by the government and private actors as New Zealand reduces its greenhouse gas emissions. It provides an initial assessment of these pathways under different emissions reductions targets but does not yet explore how strategies perform across uncertain future states of the world. These interim results provide an update for the purposes of informing the Productivity Commission's Draft Report, however this modelling remains a work in progress and results are likely to change between the interim and final reports.

The interim results seek to provide insights on the potential impacts of adopting different domestic emissions reductions targets to 2050. The main finding is that there are credible trajectories to achieving net zero greenhouse gas emissions by 2050 using current or expected technological developments. However, these trajectories should not be interpreted as the only pathways to achieving net zero by 2050. Further, these findings should be considered in light of the limitations of modelling in capturing future technological developments.

The initial findings suggest that New Zealand is likely to be able to decarbonise its economy at a cost comparable to that expected in the rest of the developed world. Each of these pathways to decarbonisation relies on three key drivers, the expansion of forestry, electrification of transport, and changes to the structure and methods of agricultural production. By combining all three of these, the results suggest New Zealand could move to a pathway consistent with net zero in the second half of the century at a 2050 emissions price of between NZD75/tCO_2e and NZD150/tCO_2e; and reach a more stringent net zero emissions constraint by 2050 with a 2050 emissions price of between NZD150/tCO_2e to NZD250/tCO_2e. These are lower than, or within the range of, emissions prices that are likely to be needed internationally to deliver the objectives of the Paris Agreement.

In all three pathways, the expansion of forestry is central to the achievement of large reductions of emissions. This is particularly the case if New Zealand is to achieve net zero greenhouse gas emissions in 2050. This reliance on forestry however, could create challenges in the longer term – with continued emissions reductions post-2050 (or maintaining emissions at around net zero) requiring New Zealand find other ways to reduce emissions. While the expansion of forest sinks cannot continue indefinitely, this is not a reason for immediate concern, with technological

developments likely to provide the potential for further cost-effective mitigation from non-forestry activities, and there are options available to support continued sequestration from New Zealand's forests after 2050. Thought will also need to be given to the mix of the different types of forest sinks. Native reforestation reduces emissions more gradually than plantation forestry but stores more carbon over the long-term and provides other environmental benefits.

The electrification of transport occurring worldwide will play a large role in supporting New Zealand's emissions reduction objectives. With a comparatively old vehicle fleet and a low emissions electricity system, the move to electric vehicles allows New Zealand to make the transition from a highly emissions-intensive transport fleet to one with a very low carbon footprint within a short time-period.

In all three pathways, emissions reductions in the agricultural sector are delivered through a mix of technological and structural change. With emissions intensity improvements, it appears that dairy production may be able to expand, although this expansion may be limited due to separate water quality concerns. Even with intensity improvements, the area of land in beef and sheep farming is likely to contract, in a continuation of recent trends. Some sheep/beef farmers might supplement their income by investing in plantations, others might choose to fence off higher altitude land to enable regeneration of native forest. The scale of this shift will be driven by demand for land from an expanding forest sector, increasing the opportunity costs of maintaining livestock.

These results also provide general findings, that greater technological change and early action through higher emissions prices may help to constrain long-term costs. Choices made now will have long term consequences, for instance assets, such as cars and industrial process heat boilers may remain in operation for several decades. Likewise, a land-owner's decision to convert land may have implications for land-use over an extended period. Given these dynamics, it is important to influence these decisions sooner rather than later, to avoid locking-in higher emissions for decades. This needs to be balanced against a concern that moving more quickly than international partners may lead to emissions leakage, although this can be avoided by using appropriate policy.

These techno-policy pathways reveal the impacts of different approaches to decarbonisation in a world acting in line with the Paris Agreement. Future action is subject to uncertainty and it is both reasonable and appropriate for New Zealand to adapt its policies in response to changed circumstances and a changing evidence base over time and take steps to avoid adverse outcomes to competitiveness such as through emissions leakage. However, New Zealand's recent history shows that it can grasp opportunities, for instance through the rapid expansion of the dairy industry, created by inevitable shifts in the domestic and international business environment. Greater global action to reduce emissions will be one of many sources of change, which brings both challenges and opportunities in new and existing markets. Understanding the scale of these potential changes is central to developing an evidence-base that can inform policy advice and planning, and modelling is a valuable aid to this.

While these interim results provide an indication of what are likely to be the key drivers and trade-offs between different approaches to decarbonising the New Zealand economy, it is only

by testing assumptions against a range of potential futures that we can identify which strategies are the best for New Zealand to pursue. Given this, the next stage of modelling will investigate the potential consequences of future uncertainties in greater detail, testing strategies that may be adopted by the New Zealand government and businesses in the medium term against a wide range of potential developments over the coming decades. In doing so it will seek to build a stronger evidence base to inform decision making. However, all modelling necessarily provides an incomplete picture, and social choice requires that policymakers, and society, take account of a wider range of trade-offs in a balanced manner.

Table 1. **Glossary of terms**

Term	Definition
adaptive response	the process by which agents gradually change their behaviour as ex ante uncertain variables become realised
decisions	the choices of government and businesses to adopt certain strategies based on their expectations and preferences
expectations	judgements based on assessment of the available information regarding the likely future value of uncertain variables, such as commodity prices and technology
outcomes	the results in terms of outcomes of interest to society, such as levels of production, employment and emissions
preferences	Includes government, business and households underlying views regarding the discounting of time, risk aversion, and social preferences regarding the distribution of consumption within society, all of which influences an agents actions and choices
realisation	the realised value of uncertain variables, such as commodity prices and technology
scenarios	the pattern of decisions across society, based on generally shared expectations and preferences
strategies	the full range of policy and investment options available to the government and private actors
techno-policy pathways	combinations of scenarios and technology assumptions that represent different ways to achieve New Zealand's decarbonisation objectives
uncertainties	future uncertain exogenous variables, such as commodity prices and the rate of technological change that effect the efficacy of strategies across scenarios

Source: *Concept, Motu, Vivid Economics*

2. Scenarios, uncertainties, and techno-policy pathways

In addressing climate change, New Zealand collectively will make decisions regarding how to pursue its interests in a changing domestic and international environment. 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. However, the assessment of scenarios is made difficult by the uncertain nature of the future. Scenarios will perform differently when faced with different realisations, and a scenario that is the best in one realisation may not be in another.

Consideration of the range of uncertainties is important, with both technological developments and uncertainty regarding future market conditions – including fossil fuel prices, commodity prices and international emissions prices – influencing outcomes. In the section below, we set out an approach to developing scenarios and testing them against a range of uncertainties, to develop a structured set of evidence to support decision-making. The interrelationship between these aspects is shown in Figure 1 below.

Varying scenarios and uncertainties creates many potential combinations that could be tested to assess outcomes. An expanded assessment of scenarios and uncertainties will be conducted in the next phase of the modelling project. These interim results reduce the number of variations considered by establishing techno-policy pathways – combinations of scenarios and technology assumptions that represent different ways to achieve New Zealand's decarbonisation objectives.

Figure 1. **Conceptual framework for the modelling exercise**
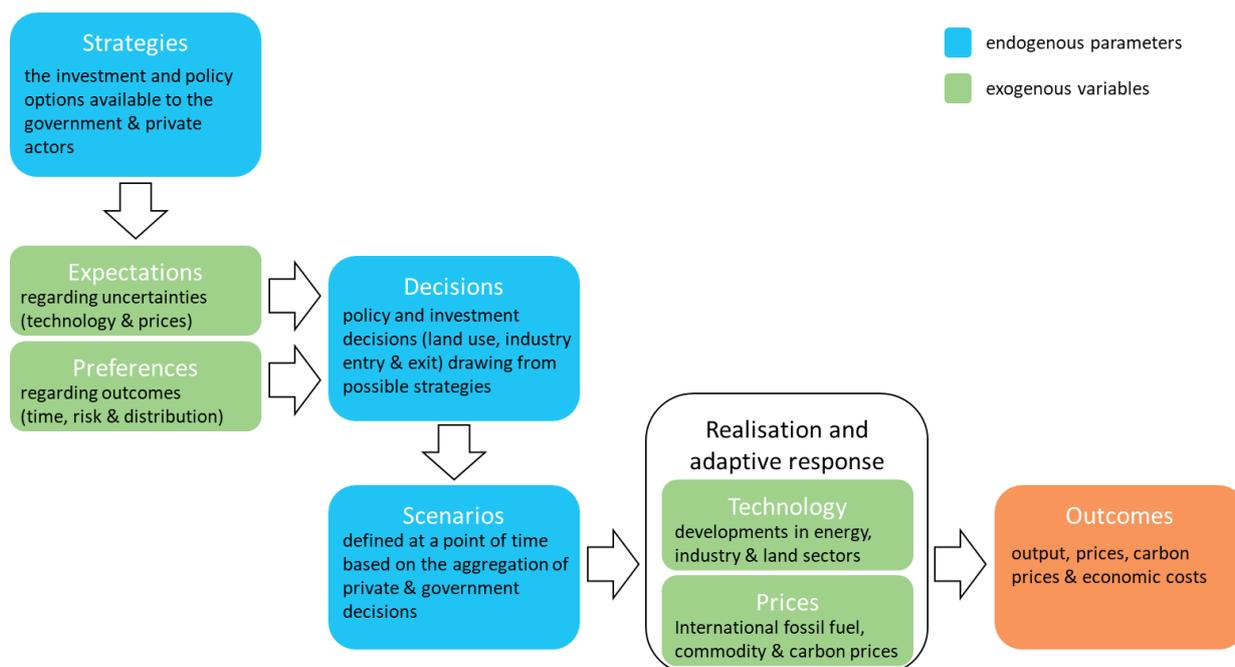
Source: Concept, Motu, Vivid Economics

2.1 Scenarios

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. But this performance is the result of not just the decisions made under these scenarios, but also the realisation of certain exogenous uncertainties that are outside the control of New Zealand based agents, and these agents' adaptive responses. These scenarios can then be compared by assessing performance regarding outcomes of interest, such as economic activity and greenhouse gas emissions, under different realised uncertainties.

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 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 regarding their future development. Similarly, the choice composition of 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. For instance, expectations regarding future commodity demand 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.

2.2 Uncertainties

Scenarios represent strategies developed in response to expectations regarding the future state of the world. However, the performance of these strategies may deviate from the expected performance due to uncertainty regarding key variables. These sets of uncertainties represent different ways in which the exogenous environment may evolve as New Zealand develops its decarbonisation strategy.

The key exogenous uncertainties for this analysis are:
  – 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 plant-based meat substitutes and cellular agriculture, 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 life of internal combustion engines, while rapid improvements in electric vehicles (EVs) and reductions in their cost could accelerate the transition away from fossil fuels.

Fossil fuel and commodity prices 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 prices and their evolution over time can offer rich interpretations as to their underlying drivers. For instance, a scenario with low fossil fuel prices, high prices for carbon intensive manufactured goods, and low prices for carbon negative forest products is consistent with ambitious global action and high global emissions prices. Relative emissions prices are a key determinant of emissions costs between jurisdictions, and differences in emissions prices can be a driver of carbon leakage. In a Paris Agreement consistent world, we would expect increased linking of carbon markets – directly or indirectly – as jurisdictions seek to increase gains from trade and reduce mitigation costs, causing international emissions prices to track each other more closely.

Common inputs are adopted for underlining economic and social trends. For the purposes of this analysis, three variables are most important to emissions, and economic outcomes:
  – the level of population
  – the baseline rate of economic growth
  – exchange rates

Population and domestic economic growth rates are more important for emissions from energy and transport, where demand is determined by domestic consumption, and are less influential for trade exposed industries such as agricultural commodities and the metals sector. Exchange rates however will be more influential for determining demand from export exposed sectors, through their impact on commodity prices.

2.3 Techno-policy pathways

Techno-policy pathways are defined as the combination of scenarios, with the technology assumptions that would be consistent with the decisions made under these scenarios. To define pathways, we assume worlds that differ based on agent's expectations regarding the rate of technological change, future domestic and export demand, and its impact on the composition of New Zealand's economy. These techno-policy pathways then also assume that these expectations regarding technological change are realised in practice.

Government policy will be a key determinant of when and how New Zealand reduces it emissions. Amongst the policies available to it, carbon pricing is central, as it provides economy-wide incentives that encourage business and individuals to consider the costs of emissions when making investment and consumption decisions. In general governments can

choose to set the price of emissions (through an emissions tax) or its quantity (through an emissions trading system), while a range of related policy decisions regarding sectoral coverage, the use of international emissions reductions or the provision of free allocations to industry may affect the scale of emission reductions achieved and their economic cost. However, the government may also adopt a range of other policies that operate alongside or instead of carbon pricing. For instance, it may consider policies that directly change the electricity mix, expand public transport, increase uptake of EVs or support the expansion of native forestry in the land sector.

In some cases, the government may act address other externalities which impact on consumers' technology choices which also have greenhouse gas implications. For instance, in transport externalities regarding respiratory health and congestion could be a driver of policy which impacts the relative economics of transport demand and mode choice.

Businesses will also make decisions based on expectations regarding the development of technologies, prices, and policies. For instance, regarding the operation of existing electricity generation or industrial facilities, investment in new electricity generation facilities, and regarding the use of land for agriculture or forestry.

Given this context, we develop three distinct techno-policy pathways:

1. **Policy Driven Decarbonisation** – this pathway sees slow, sector-neutral, technological change which means ambitious policy action, specifically a high emissions price, is required to achieve net zero emissions. This pathway predominantly relying on currently-available mitigation options, such as the expansion of the forestry sector (including policy to support native afforestation) and contraction of the pastoral agriculture. In the transport sector the government provides further incentives to support public and active transport and electric vehicles (EVs) develop at a moderate pace.

2. **Disruptive Decarbonisation** – this pathway 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. A shift in global demand patterns supports the expansion of horticulture and reductions in dairy. EVs spread rapidly due to low costs and supportive policies and consumer preferences. The reduction in the cost of renewables is reflected in the closure of coal generation capacity, and a reduction in baseload gas generation capacity. In this pathway, aluminium and steel plants choose to close in response to expectations that global technological developments and market shifts will reduce demand for these products.

3. **Techno-optimist** – this pathway 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. Recent trends to land conversion for dairy continue at a modest rate. In transport, this is reflected through only slow rates of electrification.

These pathways are illustrated in **Error! Reference source not found.** below.

Figure 2.   **Illustrative mapping of pathways against expectations that drive decision-making**
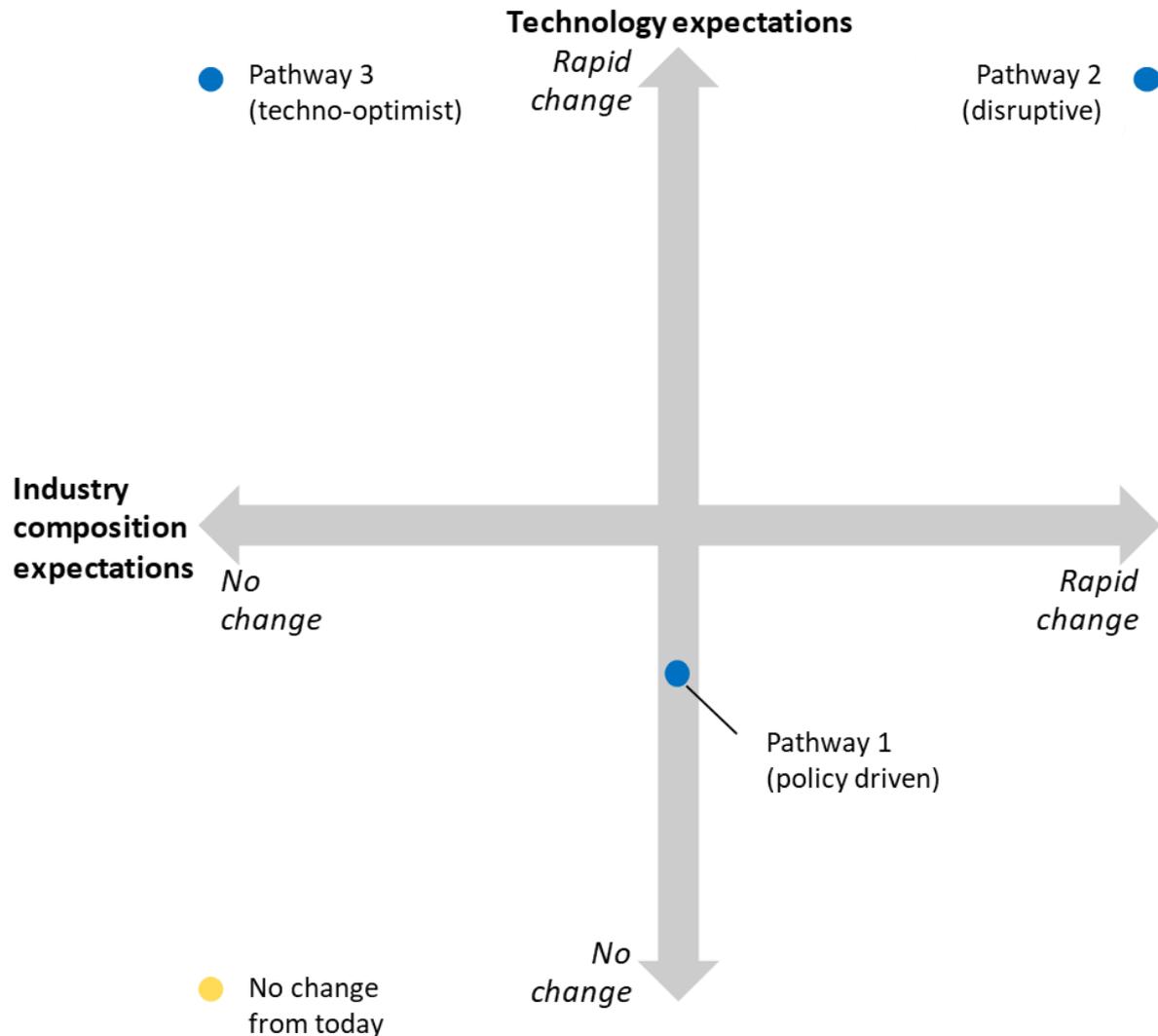
To provide comparability, techno-policy pathways are assessed using a single set of assumptions regarding other uncertainties (fossil fuel, commodity, and international emissions prices).

The pathways also represent differences between demand side and supply side mitigation.
The Policy Driven pathway is characterised by policy that drives domestic demand substitution.
By contrast, the Disruptive and Techno-optimist pathways are defined by supply side responses to different technology sets: in the Disruptive pathway technological change reinforces rapid changes in global demand patterns; while in the Techno-optimist pathway see the emergence of new technologies that reduce emissions intensity and enable existing industries to continue.

2.4 Emissions targets

These interim results seek to test several pathways for achieving significant domestic emissions reductions targets. We have adopted two targets for this purpose:
- net emissions to be below 25 $MtCO_2e$ in 2050.
- net emissions to be below 0 $MtCO_2e$ in 2050.

These targets were developed considering a range of potential emissions reduction trajectories which New Zealand could follow to achieve net zero greenhouse gas emissions, as shown in Figure 3 below. The 25 $MtCO_2e$ target is consistent with a range of emissions trajectories capable of achieving net zero greenhouse gas emissions soon after 2050 and is broadly consistent with a net zero *long-lived* greenhouse gas target for 2050. The 0 $MtCO_2e$ target represents the more stringent aim to achieving net zero greenhouse gas emissions within this timeframe.

Figure 3. **Trajectories for emissions reductions consistent with net zero by 2075**
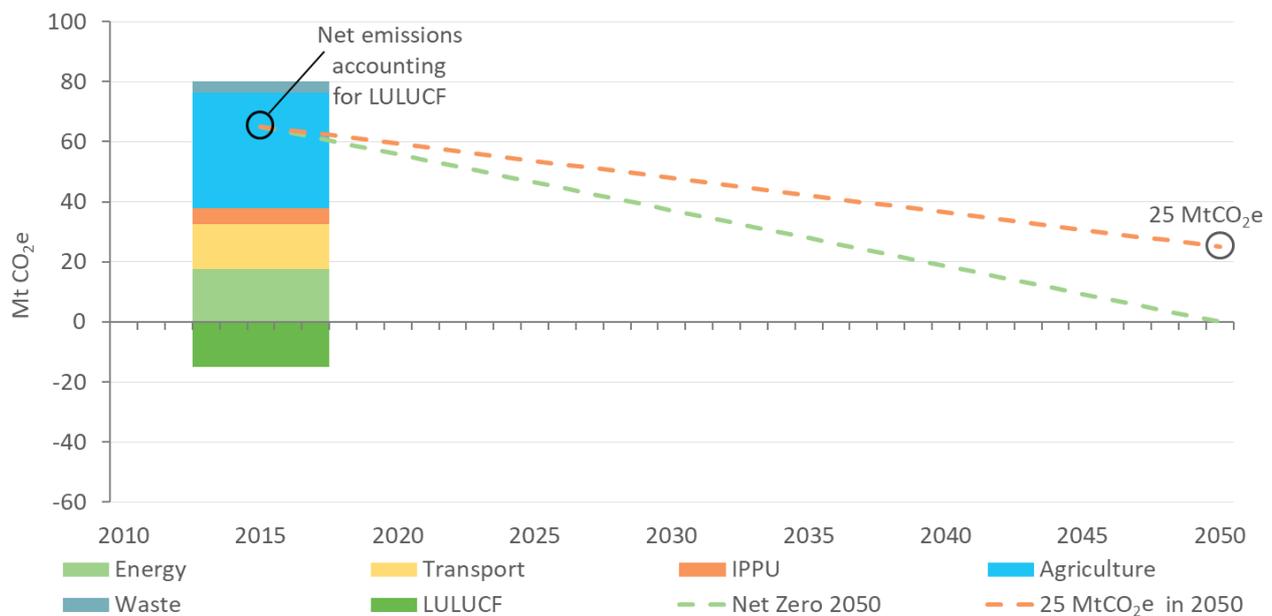
Note: *The trajectories shown are linear, but different trajectories could achieve the emissions constraint over time. The 25 $MtCO_2e$ trajectory achieves net zero greenhouse gas emissions in the 2070-75 period. Trajectories start from estimated current emissions level using an updated accounting methodology, utilising an averaging approach to sequestration from forestry.*

Source: *Concept, Motu, Vivid Economics*

3. Methodology and approach

The modelling draws on two models, Concept Consulting's energy and industry model (ENZ), and Motu Economic and Policy Research's Land Sector in Rural New Zealand (LURNZ) model. Together, these models capture New Zealand's greenhouse gas emissions profile and provide a robust base for testing the implications of policy and investment strategies across the economy. This section highlights the key characteristics of the models with a full description of the models provided in the Technical Appendix.

The models are 'structural' models 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.

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 marginal abatement cost (MAC) curves interacting with the assumed emissions price.

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 observed land-use choices to factors that affect these choices. These include various geophysical characteristics of the land, as well as proxies for cost of market access such as distance from population centres and ports and land tenure (Maori freehold tenure compared to general freehold tenure).

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.[1]

These models, like all models, have limitations. First, the models focus on accurately depicting the incentives and outcomes within their specific sectors of focus. This means that while they provide a richness of detail that can be lacking in other models, they are unable to provide estimates of aggregate whole-of-New Zealand economic cost of different pathways. Second, by linking two models, it is not possible to capture all potential dynamic effects operating between the energy and industry sectors and the land sector. Finally, because the models are discrete tools, linking them has challenges. Both models use emissions prices as an input to solve the allocation of activity in the energy and land sectors respectively. Each pathway was run with several emissions price paths in each model, with linear interpolation between runs that over- and underachieved the target for each pathway. Linear interpolation can have drawbacks, as it may lead to spurious results where the relationship between emissions prices and a given outcome is not linear, for example the close of a large manufacturing plant.

This interim stage of modelling focuses on accurately defining and depicting the three techno-policy pathways. As such, it uses a standard set of assumptions regarding fossil fuel prices, commodity prices, and international emissions prices. In the next stage of the project, these uncertainties will be allowed to vary, and agents' expectations regarding future price and technological change may prove incorrect. This will allow testing of how the different scenarios perform under different, unexpected states of the world.

Table 2 outlines how techno-policy pathways have been translated into modelling assumptions. Further information on the ENZ and LURNZ models is provided in the Technical Appendix.

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[1] See the technical appendix for further details.

Table 2. **Key pathway assumptions**

Variable	Policy Driven	Disruptive	Techno-optimist
General			
ETS coverage	All sectors including agriculture	All sectors including agriculture	All sectors including agriculture
ETS free allocation	From 2015-20, allocation as per NZ ETS, with agriculture receiving a 90 per cent allocation. From 2020, fast withdrawal of assistance, withdrawn at 3 percentage points from 2020 to 2030 and 5 percentage points a year thereafter	From 2015-20, allocation as per NZ ETS, with agriculture receiving a 90 per cent allocation. From 2020, fast withdrawal of assistance, withdrawn at 3 percentage points from 2020 to 2030 and 5 percentage points a year thereafter	From 2015-20, allocation as per NZ ETS, with agriculture receiving a 90 per cent allocation. From 2020, slow withdrawal of assistance, withdrawn at 1 percentage points from 2020 to 2030 and 3 percentage points a year thereafter
Population growth (average to 2050)[2]	1.0 per cent per year	1.0 per cent per year	1.0 per cent per year
Industry			
Iron & Steel	Future operation endogenously modelled based on New Zealand and international emissions prices	Exogenously specified closure in 2025	Future operation endogenously modelled based on New Zealand and international emissions prices
Aluminium	Future operation endogenously modelled based on New Zealand and international emissions prices	Exogenously specified closure in 2025	Future operation endogenously modelled based on New Zealand and international emissions prices
Industrial process heat fuel-switching away from fossil	Endogenously modelled based on pathway emissions prices	Endogenously modelled based on pathway emissions prices	Endogenously modelled based on pathway emissions prices

[2] Population growth in the early years of the projection is significantly greater than in the later years, as per Stats NZ central forecast.

Variable	Policy Driven	Disruptive	Techno-optimist
Refrigerant emissions	Emissions reduce in line with Montreal Protocol commitments (declining to zero by 2043), with faster achievement modelled in scenarios with high international carbon prices.	Emissions reduce in line with Montreal Protocol commitments (declining to zero by 2043), with faster achievement modelled in scenarios with high international carbon prices.	Emissions reduce in line with Montreal Protocol commitments (declining to zero by 2043), with faster achievement modelled in scenarios with high international carbon prices.
Waste	Endogenously modelled based on pathway emissions prices	Endogenously modelled based on pathway emissions prices	Endogenously modelled based on pathway emissions prices
Transport			
Rate of EV battery cost reductions	Costs decline at 6 per cent per annum	Costs decline at 8 per cent per annum	Costs decline at 4 per cent per annum
Extent of mode-shifting to public transport, walking & cycling, and 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.	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.	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.
Vehicle scrappage rates	Scrappage rates continue at historic scrappage rates.	Scrappage rates 25 per cent higher than historic rates.	Scrappage rates 25 per cent lower than historic rates.
Electricity			
Huntly coal-fired station	Operation and retirement endogenously modelled based on technology costs, fuel prices, and emissions prices	Exogenously specified closure in 2025	Operation and retirement endogenously modelled based on technology costs, fuel prices, and emissions prices
TCC combined-cycle gas turbine (CCGT) power station	Operation and retirement endogenously modelled based on technology costs, fuel prices, and emissions prices	Exogenously specified closure in 2025	Operation and retirement endogenously modelled based on technology costs, fuel prices, and emissions prices

Variable	Policy Driven	Disruptive	Techno-optimist
E3p combined-cycle gas turbine (CCGT) power station	Operation and retirement endogenously modelled based on technology costs, fuel prices, and emissions prices	Operation and retirement endogenously modelled based on technology costs, fuel prices, and emissions prices	Operation and retirement endogenously modelled based on technology costs, fuel prices, and emissions prices
Rate of renewable technology (wind, solar, geothermal) cost improvement	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 1.5 times the rates in the Policy Driven pathway	Cost reductions of 0.5 times the rates in the Policy Driven pathway
Rate of residential and commercial energy efficiency improvement	Energy efficiency improvements are disaggregated across the uses for which gas is employed (mostly space heating and water heating) and consumers (residential, commercial, and agricultural). 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	Energy efficiency improvements are disaggregated across the uses for which gas is employed (mostly space heating and water heating) and consumers (residential, commercial, and agricultural). 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	Energy efficiency improvements are disaggregated across the uses for which gas is employed (mostly space heating and water heating) and consumers (residential, commercial, and agricultural). 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
Fuel switching to electricity from direct use of gas for space and water heating	Endogenously modelled based on pathway emissions prices	Endogenously modelled based on pathway emissions prices	Endogenously modelled based on pathway emissions prices

Agriculture and forestry

Commodity Prices	Commodity price forecasts from the 'Situation and Outlook for Primary Industries' 2017. Prices held	Commodity price forecasts from the 'Situation and Outlook for Primary Industries' 2017. Prices held	Commodity price forecasts from the 'Situation and Outlook for Primary Industries' 2017. Prices held

Variable	Policy Driven	Disruptive	Techno-optimist
	constant beyond 2021, the last projection year of the outlook.	constant beyond 2021, the last projection year of the outlook.	constant beyond 2021, the last projection year of the outlook.
Emissions Intensity	Continuous improvement (year on year) in the efficiency of GHG emission per unit of product produced, with dairy and sheep/beef intensity based on the 'minimum efficiency' baseline scenario from Reisinger et al (2016).[3]	Continuous improvement (year on year) in the efficiency of GHG emission per unit of product produced, with dairy and sheep/beef intensity based on the 'minimum efficiency' baseline scenario from Reisinger et al (2016).	Continuous improvement (year on year) in the efficiency of GHG emission per unit of product produced, with dairy and sheep/beef intensity based on the 'minimum efficiency' baseline scenario from Reisinger et al (2016). In addition, methane vaccine available after 2030: reduces dairy livestock emissions by 30 per cent, sheep-beef livestock emissions by 20 per cent. 100 per cent adoption rate assumed.
Forestry sequestration	Payments to 21years after planting based on NIR lookup table. This reflects expectation of future policy. Average annual rate is 31.83tCO$_2$e/ha. No payments/removals after that.	Payments to 21years after planting based on NIR lookup table. This reflects expectation of future policy. Average annual rate is 31.83tCO$_2$e/ha. No payments/removals after that.	Payments to 21years after planting based on NIR lookup table. This reflects expectation of future policy. Average annual rate is 31.83tCO$_2$e/ha. No payments/removals after that.
Scrub/native sequestration	6.5tCO$_2$e/ha emission/sequestration for each hectare change in total area throughout simulation period	6.5tCO$_2$e/ha emission/sequestration for each hectare change in total area throughout simulation period	6.5tCO$_2$e/ha emission/sequestration for each hectare change in total area throughout simulation period

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[3] Reisinger, A. et al., 2016. Modelling Agriculture's Contribution to New Zealand's Contribution to the Post-2020 Agreement, Wellington. http://www.nzagrc.org.nz/policy,listing,312,modelling-agricultures-contribution-to-new-zealands-contribution-to-the-post-2020-agreement.html

Variable	Policy Driven	Disruptive	Techno-optimist
Dairy area	No new conversions from 2025, to approximate the impact of Councils implementing water quality limits in their regions.[4]	No new conversions from 2025, to approximate the impact of Councils implementing water quality limits in their regions.	No new conversions from 2025, to approximate the impact of Councils implementing water quality limits in their regions.
Horticulture emissions	1.0 tCO$_2$e/ha. This is close to mean emissions per hectare from kiwifruit and cropping.[5]	1.0 tCO$_2$e/ha. This is close to mean emissions per hectare from kiwifruit and cropping.	1.0 tCO$_2$e/ha. This is close to mean emissions per hectare from kiwifruit and cropping.
Horticulture Area	Horticulture Area: linear increase to 500,000 ha by 2050.	Horticulture Area: linear increase to 1,000,000 ha by 2050.	Constant
Urban Area	Constant[6]	Constant	Constant
Native scrub area	Endogenous and exogenous. Exogenous component represents a policy push toward natives amounting to 33 per cent of new forests	Endogenous	Endogenous

Source: Concept, Motu, Vivid Economics

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[4] The Freshwater NPS directs regional councils to set objectives for the state of fresh water bodies in their regions and to set limits on resource use to meet these objectives. The Freshwater NPS must be implemented by 31 December 2025.

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[5] Based on horticultural emission factors provided by the NZ Agricultural GHG Research Centre.

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[6] Urban area is less than 1 per cent of total land use in New Zealand.

4. Results

The results below paint a picture of a New Zealand changed noticeably, but not drastically. It suggests a gradual evolution of New Zealand's economic structure enabling it to achieve its decarbonisation objective under a variety of potential futures. It suggests the movement away from some traditional industries, and the creation of new ones, and points to the important role that new technologies will play in enabling the creation of a low-emissions economy.

In the section below, we examine how these pathways perform in terms of their impact on key attributes including:
— net and gross emissions
— emissions prices
— the structure of the energy and industry sectors
— the structure of the agriculture and forestry sectors

An overview of key results metrics is provided in Table 3, at the end of this section.

4.1 Emissions

While achieving similar final emissions levels in 2050 under the 25 MtCO$_2$e and 0 MtCO$_2$e targets respectively, the three pathways take different trajectories resulting in different cumulative emissions over the period.[7] The Disruptive Decarbonisation pathway has the lowest cumulative emissions, driven by relatively rapid decarbonisation (compared to other pathways) in the 2020's. Under the Disruptive 25 MtCO$_2$e pathway (DD25) emissions over the period 2016-50 reach only 1.6 gigatonnes (GtCO$_2$e) – notably lower than the Techno-optimist (TO25) or Policy driven (PD25) pathways which each reach 1.8 GtCO$_2$e. Under the more stringent targets, cumulative emissions in the Disruptive pathway (DD0) reaches 1.3 GtCO$_2$e, compared to just over 1.5 GtCO$_2$e in the Techno-optimist pathway (TO0) and 1.6 GtCO$_2$e in the Policy Driven pathway (PD0). Comparing the Techno-optimist and Policy driven pathways, although they achieve similar cumulative emissions outcomes over the period (2016-2050), in the period to 2030 the Policy Driven pathways achieve greater emissions reductions than the Techno-optimist pathways. However, the introduction of a methane vaccine in 2030 sees emissions in the Techno-optimist pathways drop rapidly and remain below those of the Policy Driven pathway for most of the period to 2050.

The difference in cumulative emissions reductions is partially by assumption, with the Disruptive pathways featuring earlier structural change driving larger near-term emissions reductions even with a lower emissions price. Similarly, higher cumulative emissions in the Policy Driven pathways is, in part, due to the assumed increase in native afforestation/reforestation in these pathways which reduces emissions more gradually than plantation forestry.

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[7] Due to modelling constraints the Policy Driven and Techno-optimist pathway reach close to, but do not reach 0 MtCO$_2$e in these results, with PD0 reaching emissions of 3.9 MtCO$_2$e in 2050 and TO0 reaching emissions of 0.4 MtCO$_2$e in 2050.

Figure 4. **All pathways deliver large reductions in emissions**
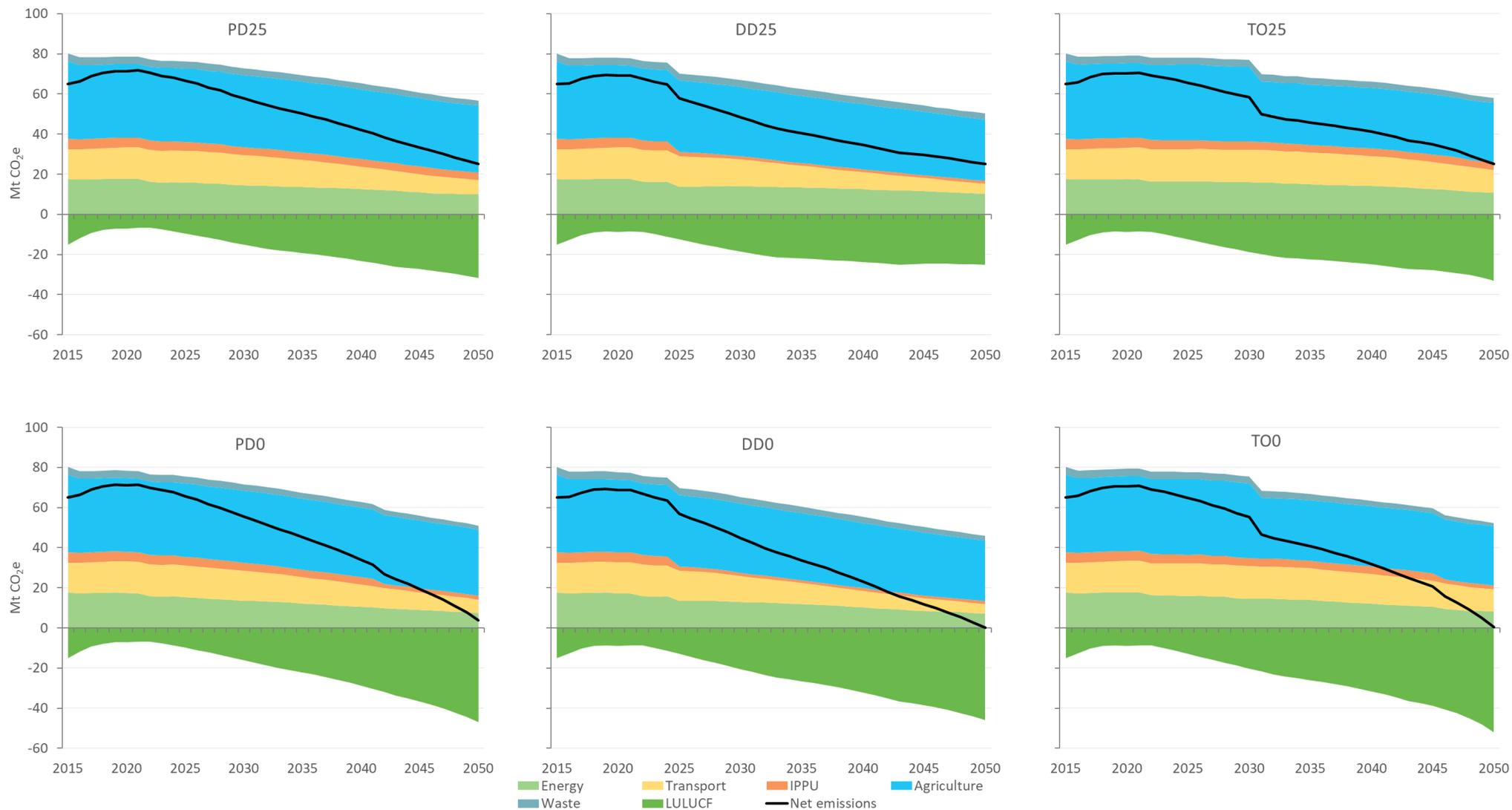
The divergence of pathways occurs primarily after 2030, after which the 0 MtCO2e targets reduce emissions at a noticeably faster rate, this is shown in Figure 5 below.

Figure 5.   **Pathways feature very different emissions profiles over time**
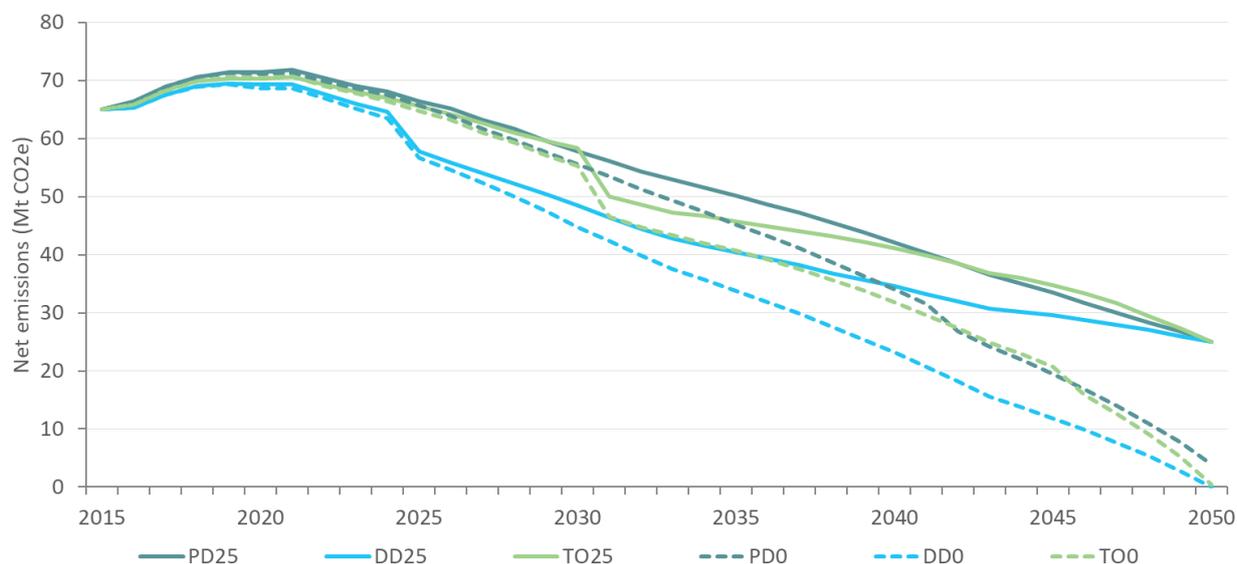
*Source:*   *Concept, Motu, Vivid Economics*

This difference in the shape of emissions trajectory is in part driven by the differing levels of LULUCF to meet the 2050 target. While all pathways see an increase in sequestration from forestry compared to current levels, the Policy Driven and Techno-optimist pathways rely more heavily on the expansion of forestry to deliver sequestration. This means that gross emissions in 2050 are highest in the Techno-optimist pathways, reaching 58.0 MtCO$_2$e in the TO25 pathway and 52.4 MtCO$_2$e in the TO0 pathway. The Policy Driven pathways rely nearly as heavily on forestry, with gross emissions reaching 56.7 MtCO$_2$e in the PD25 pathway and 51.0 MtCO$_2$e in the PD0 pathway. In comparison, the Disruptive pathways use less forestry mitigation, with gross emissions falling to 50.2 MtCO$_2$e in the DD25 pathway and 45.9 MtCO$_2$e in the DD0 pathway. This has important implications for mitigation post-2050, as it means that to achieve or maintain net zero greenhouse gas emissions, the Techno-optimist and Policy Driven pathways will either need to continue to rely on greater amounts of forestry sequestration, or make up the mitigation gap with other, potentially more expensive, options.

4.2 Emissions prices

Emission price trajectories in the period to 2030 are exogenously determined, reflecting the expectations embedded within the pathways. Prices are assumed to be lower to 2030 in each pathway under a 25 MtCO$_2$e. In under the PD25 prices are assumed to rise relatively quickly, to reach NZ$55/tCO$_2$e in 2030, reflecting stronger early policy action given the expectation of slow technological change. By contrast, in DD25 and TO25 prices rise to reach only about NZ$30/tCO$_2$e reflecting a slower start relying heavily on the expectation of technological breakthroughs. In the

0 MtCO$_2$e pathways, prices rise more rapidly, reaching NZ\$80/tCO2e by 2030 in PD0, and NZ\$55/tCO$_2$e in DD0 and TO0.

Figure 6. **Emissions prices increase steadily from current levels**
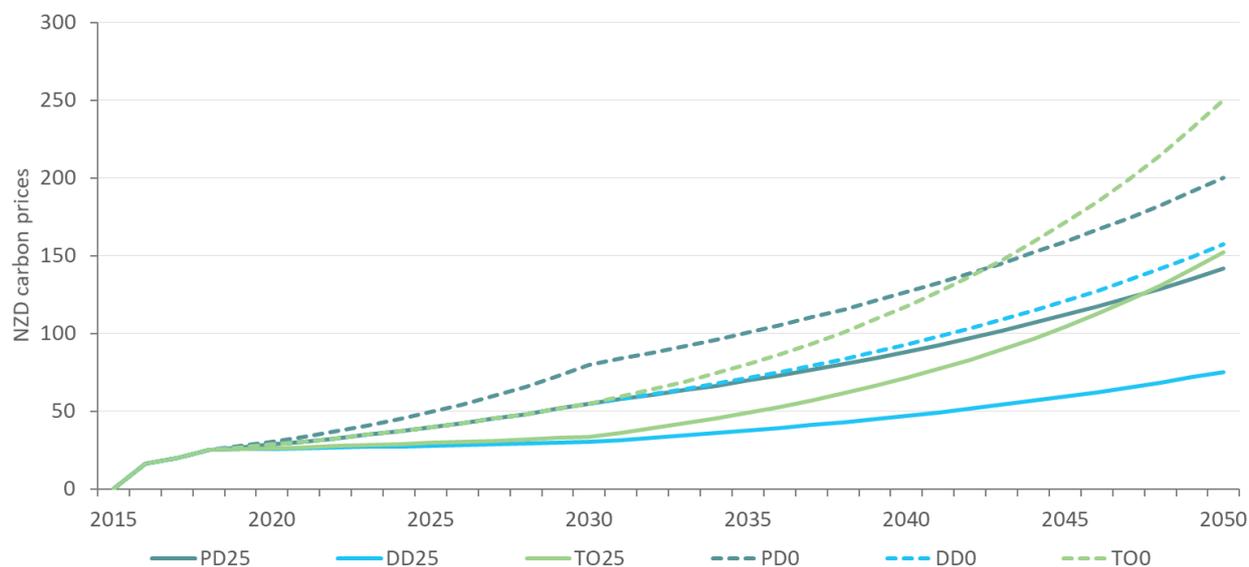
Beyond 2030, the emissions prices are model outcomes, capturing what the models assess is necessary to achieve the different domestic target. The analysis reveals significant differences in the emissions prices needed to reach targets both between pathways and targets. The Disruptive pathways have far lower emissions prices than both the Policy Driven and Techno-optimist pathways, reaching NZ\$75/tCO$_2$e in DD25 and NZ\$157/tCO$_2$e in DD0. In comparison, the emissions price in PD25 and TO25 reach NZ\$142/tCO$_2$e and NZ\$152/tCO$_2$e respectively. The PD0 pathway sees an emissions price of NZ\$200/tCO$_2$e in 2050 to reach emissions of 3.9 MtCO$_2$e, while even with a price of NZ\$250/tCO$_2$e in 2050 the TO0 pathway sees net emissions remain marginally above zero at 0.4 MtCO$_2$e. These price trajectories are shown in Figure 6 above.

Notably, the emissions-price trajectories for the Techno-optimist pathways are below the Policy Driven pathways for much of the total period, before rising rapidly to exceed emissions prices in the Policy Driven pathways during the 2040s. This reflects a range of drivers, but the lower prices in the Policy Driven pathways is indicative of the value of taking early action to avoid more extreme action later to achieve a given emissions target. In addition, the high prices in the Techno-optimist pathways relative to the Disruptive pathways reflects the interplay between technology, structural change, and efficiency improvements. Despite significant reductions in emissions intensity under the Techno-optimist pathway, it still maintains relatively emissions intensive activities. This means that the carbon price must do more of the work to drive decarbonisation than under the Disruptive pathway, where the change in technology is towards even less emissions intensive activities.

4.3 Energy and industry

New Zealand's electricity mix is already very low emissions by global standards, and, as such, it does not feature heavily as a source of mitigation. However, the modelling does reveal a major shift in New Zealand's energy system, as it expands its electricity system to handle increased rates of electrification, predominantly in transport but also in industry and the residential sector. In all pathways, electricity demand grows by more than 45 per cent from 2015 levels. It grows least in the Techno-optimist pathways, where there are lower rates of EV penetration. The Disruptive pathways see slightly higher demand growth, with high levels of vehicle electrification somewhat offset by the assumed closure of the Tiwai aluminium smelter from 2025. The largest growth is in the Policy Driven pathways, with moderate rates of electrification and higher industrial demand seeing total generation increase by 58 per cent in PD25 and by 63 per cent in PD0.

New Zealand's electricity system moves to higher proportions of renewable energy, but with some fossil generation remaining to provide infrequent 'firming' generation. Most of the growth in electricity demand is met by the building of new renewable generation. Further, the remaining combined cycle gas turbine (CCGT) generators are projected to be displaced from baseload operation by new renewable generation as emissions prices rise.[8] There remains a need for some peaking fossil generation to manage periods of particularly high demand and/or low renewable output – for instance, dry years where hydroelectricity generation is low. Further, some industrial gas-fired cogeneration is projected to be remain operational at projected emissions prices.

The extent to which residual peaking fossil generation is required is sensitive to emissions prices and fuel costs. These factors will differ between coal-fired Rankine generators, CCGTs, or gas-fired peaking generators. This is inherently complex, with factors such as industry composition having a bearing on the price of providing gas fired peaking generation. The extent of peaking generation required is also sensitive to:
– variations in the composition of new renewable generation capacity; with a future with a greater proportion of (variable) wind generation requiring more peaking generation than a future with a greater proportion of baseload geothermal generation).
– variations in the extent of future demand-side interaction in the market; particularly the degree to which EV demand is dynamic by concentrating charging in low-demand periods, and in returning power to the grid at times of high demand.
– future emissions prices, technology costs and storage costs; which influences trade-offs between over-building renewable capacity, relying on peaking generation, or investing in storage such as through batteries or pumped hydroelectric-generation capacity.

Wind generation is expected to capture most of growth in electricity demand, alongside new geothermal and solar generation. The extent to which these different technologies meet the growth in demand and displace existing fossil generation is sensitive to rates of technological change and the relative costs of technology, future emissions prices and the extent to which storage and demand side response can provide low-cost balancing of variable wind or solar

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[8] 'Baseload' generation refers to generation which runs at almost all times. This contrasts with 'peaking' generation which is only called upon in times of particularly high demand, and/or periods of particularly low generation from 'variable' renewable generators

generation. Different plausible futures for these different drivers, can materially affect the extent to which the growth in renewable generation is from wind, geothermal and solar. Although there is inherent uncertainty as to the composition of the generation mix (both the type of new renewables, and the composition of remaining peaking fossil generation), there is a high degree of confidence that it is economic to build additional renewables to displace existing fossil generation from baseload duties at projected emissions prices. This will provide the largest gain in terms of reducing carbon emissions from the power generation sector. With the retirement of the baseload CCGT generators and a reduction in Rankine generation, emissions from geothermal generators are larger than the emissions from the remaining Rankine and Peaker generators (whose role is principally dry-year and winter generation).[9] Figure 7, below, shows these changes.[10]

Despite these large changes, energy system network and generation costs remain at current levels or slightly increase. Total wholesale energy and network costs are estimated to increase slightly in the Policy Driven and Techno-optimist pathways and remain broadly stable in the Disruptive pathway.[11]

Figure 7. **All pathways involve substantial growth in electricity demand, provided mainly by renewables**
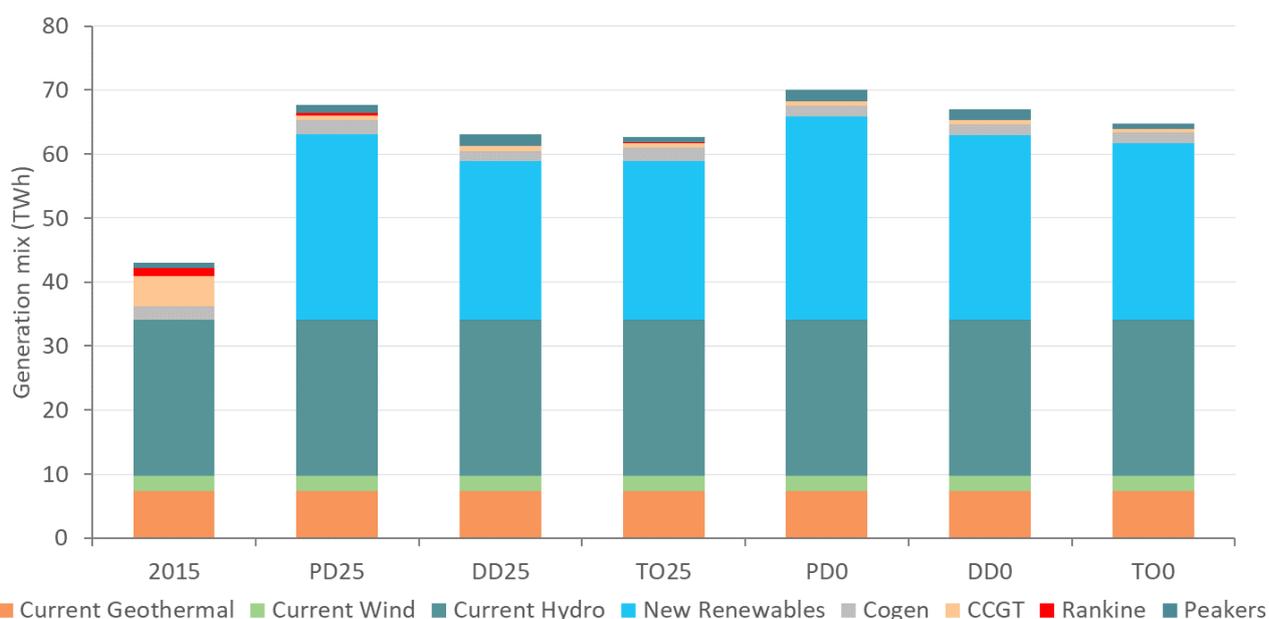
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[9] This transition of roles for the Rankine generators has already started to occur, with 2016 being the first year when emissions from geothermal generation were larger than emissions from coal-fired generation.

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[10] Runs to date suggests multiple options for the cost-effective supply of low carbon electricity. In the figure presented, most new electricity generation was projected to be provided by wind, however estimates of the composition of renewable generation are currently being updated. As such, the final publication will include a detailed breakdown of the composition of electricity generation.

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[11] Note that these costs provide an incomplete picture of broader energy system costs, and do not account for other costs, for instance incurred through improved building stock or energy efficiency investments.

The largest driver of emissions reductions in the energy sector is the rapid expansion of the electric vehicle (EV) fleet. Over the last five years battery technologies have developed rapidly, reflected in reduced battery and electric vehicle costs that have allowed then to start to compete on cost with conventional vehicles. This has, in turn, spurred new investment and policy changes, with many countries envisioning fully phasing out new internal combustion engines in light vehicles over the next two to three decades.

As a small economy, New Zealand will be an adopter, rather than a driver of these new technologies. EVs are nonetheless likely to play a major role in decarbonising the New Zealand economy. Under all pathways, uptake of light electric vehicles occurs rapidly, reaching about 80 per cent of the light vehicle fleet by 2050 under the Disruptive pathways and almost 65 per cent in the Policy Driven pathways. Take up is slower under the Techno-optimist pathways, as slower advances in battery technology somewhat reduces EV uptake. Nonetheless, even in this pathway, EVs reach almost 40 per cent of the light vehicle fleet by 2050, shown in Figure 8 below.

Emissions from the heavy vehicle fleet are also constrained by the expansion of EVs. In the Disruptive pathways, emissions from heavy vehicles decline by 35-39 per cent to 2050. Similarly, the Policy Driven pathways see heavy vehicle emissions decline by 5-9 per cent, whereas in the Techno-optimist pathways, they increase by 30-34 per cent. The slower transition to EVs for the heavy vehicle fleet is primarily due to vehicle weight being a significant driver of the economics of heavy vehicles, with EV trucks weighing significantly more than ICE trucks.

Figure 8. **Light electric vehicles form a substantial part of the vehicle fleet in all pathways**
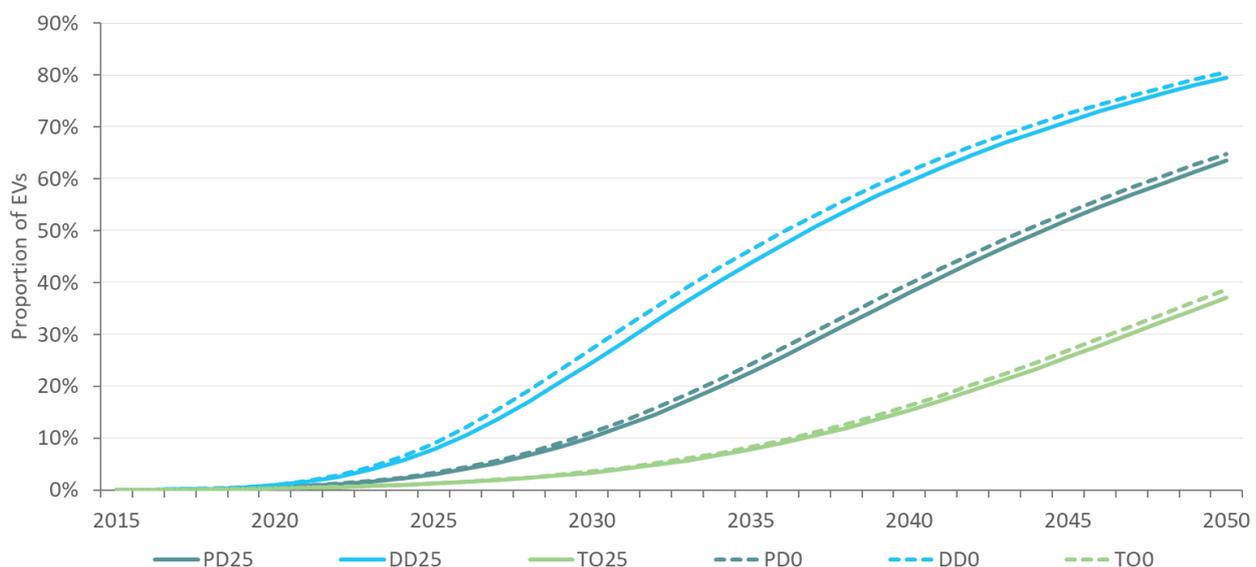
Source: Concept, Motu, Vivid Economics

Policy and consumer choices can influence the rate of EV adoption and emissions from transport more broadly. For instance, policies to increase the attractiveness of electric vehicles relative to internal combustion vehicles, or to increase vehicle turnover such that new electric vehicles are

adopted more rapidly can also have an impact. We assume that a mix of government policy and consumer preferences effects the scrappage rates of vehicles, with the Disruptive pathways including the highest vehicle scrappage rates and therefore more rapid rates of EV adoption, followed by the Policy Driven and Techno-optimate Pathways. Other policy options to reduce emissions from transport could include policies to encourage mode shifting or improve vehicle fuel economy, for instance, the Policy Driven pathway assume measures to increase adoption of public and active transport.

Upgrading the light vehicle fleet increases costs, with real vehicle purchase and maintenance costs 10-25 per cent higher in 2050 than 2015, although these costs are somewhat offset by health benefits. These cost increases reflect the degree of electrification of transport, being lowest in the Techno-optimist pathways and highest in the Disruptive pathways. Fuel costs will also differ by pathway, with the shift to greater electrification likely reducing fuel costs relative to those of petrol or diesel vehicles, and potentially offsetting higher purchase and maintenance costs.[12] A broad consideration of the costs associated with the transport system also includes externalities, for instance the costs imposed on society through congestion or health impacts. Here the Policy Driven pathways outperform the Disruptive and Techno-optimist pathways, with increased public and active transport leading to reduce congestion, land and construction costs, and reduced health externalities. Further details on these costs are provided in Table 3.

Emissions outcomes differ substantially by industry across the pathways, as shown in Figure 9 below. Under the 25 $MtCO_2e$ target pathways, the largest variance in outcomes is for iron and steel and aluminium, reflecting the assumption that in the Disruptive pathways these operations close, in response to expectations that global technological developments and market shifts will reduce demand for these products. Under the 0 $MtCO_2e$ target pathways, higher emissions prices drive large reductions in emissions from the food processing and pulp and paper sectors, reflecting a range of technical and process drivers, including electrification, biomass uptake and energy efficiency. Interestingly, under the higher emissions prices needed for the net zero in 2050 target, production of Iron and Steel also ceases in the policy driven and techno optimist pathways which does not happen in these pathways with a 25 $MtCO_2e$. This is driven by the assumption that high global emissions prices will drive a shift away from steel, which given the assessment of New Zealand steel's cost and emissions profile relative to overseas producers, could lead to closure. However, it is important to note that there are material degrees of uncertainty over such assessments.

The assumed closure of the aluminium and iron and steel industries in the Disruptive pathways leads to foregone revenues over the period to 2050. Under PD25 and TO25 however, both the aluminium and steel industries continue to produce to 2050, with the assumed closure of these industries under DD25 implying a 74 per cent loss in revenue from iron and steel and aluminium over the period 2016-50. This lost revenue is reduced slightly under the 0 $MtCO_2e$ pathways as the modelling suggests iron and steel would close by 2042 in PD0 and by 2046 in TO0. Table 3 provides further details. Note revenue may be a poor metric for the economic contribution of

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[12] This comparison has not been completed at this stage as it would require we consider not just the costs of petroleum and diesel but also apportion costs from electricity consumed.

these sectors, with costs likely to be far less than suggested by a revenue comparison. Rather, other indicators such as employment or gross value-add will provide a more accurate picture of these sectors economic contribution. Further while transitions costs are likely following the closure of industrial production facilities, in an efficient economy, most of the resources used in these industries can be expected to be re-deployed and produce value elsewhere in the medium term.

Emissions from the fugitive and waste sectors also decline. Fugitive emissions from coal and gas decline significantly as electricity generation using these fuel sources declines, while emissions from geothermal are broadly stable reflecting its ongoing importance in New Zealand's energy mix. This means that fugitive emissions from geothermal generation become the largest source of emissions from the electricity generation sector. Emissions in waste also decline driven by a reduction in the generation of waste across the economy and increased methane capture and combustion.

Figure 9. **Iron and steel emissions see the greatest variation in emissions among industrial sectors, across the pathways**
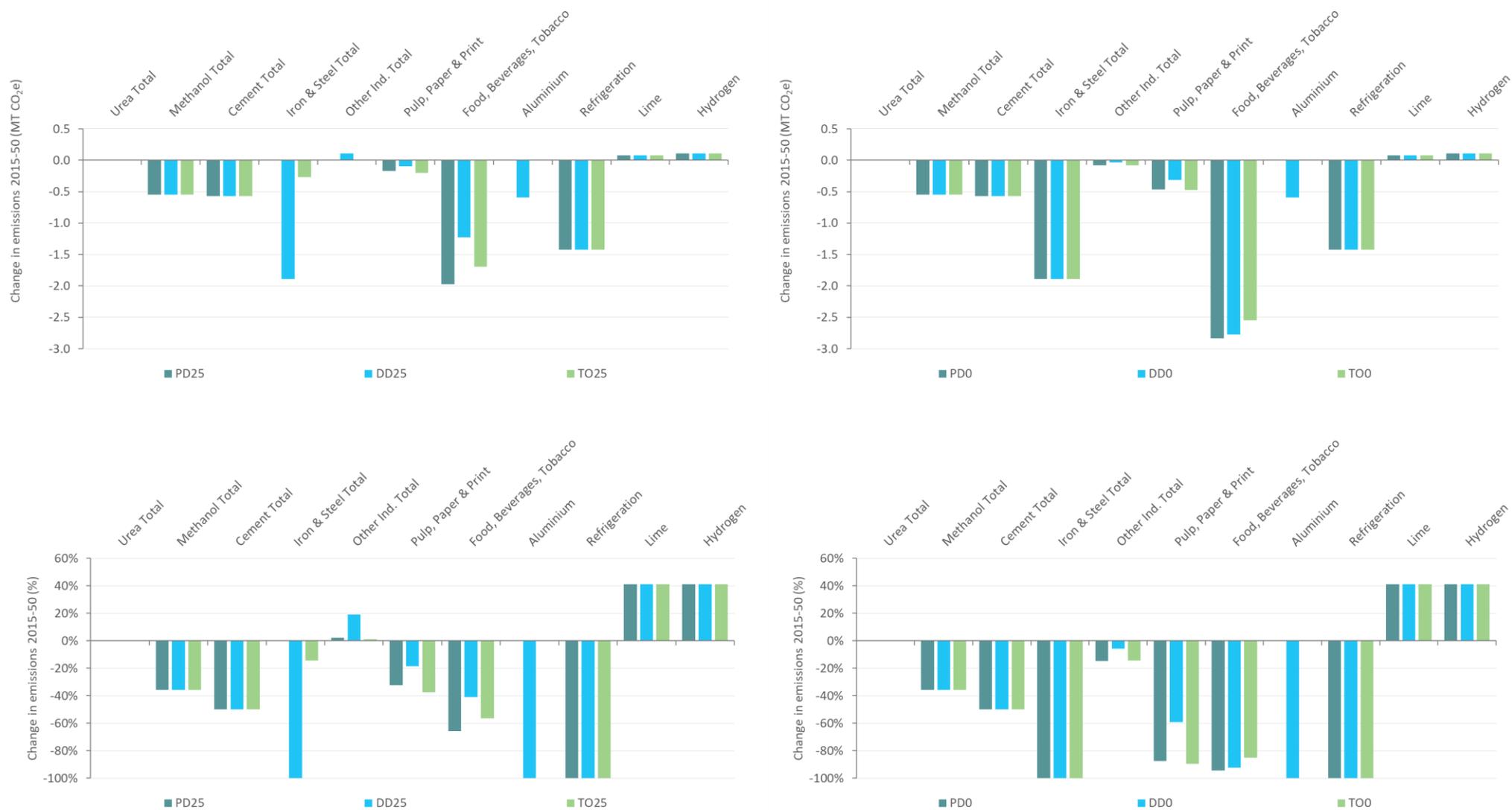
Source: *Concept, MOTU, Vivid Economics*

4.4 Agriculture and forestry

The largest driver of net emissions reductions to 2050 are the agriculture and forest sectors. New Zealand's unique emissions profile means that today, the land sector is already much more important to New Zealand's emissions profile than in comparable countries. This means achieving emissions reductions in these sectors is central to New Zealand's emissions reduction challenge.

Under all pathways, forestry sequestration increases. In the 25 MtCO$_2$e target pathways, sequestration from forestry increases from about 15 MtCO$_2$e in 2015 to reach about 25 MtCO$_2$e by 2050 in DD25, rising further to 32 MtCO$_2$e in PD25 and 34 MtCO$_2$e in TO25. However, these levels of sequestration are dwarfed by the large expansion of forestry sequestration in the 0 MtCO$_2$e target pathways as shown in Figure 10 below[13]. In these pathways, forest sequestration increases to reach over 45 MtCO$_2$e in both DD0 and PD0 and more than 50 MtCO$_2$e in TO0.

This large relative increase in forestry sequestration between the different targets implies that further expanding forestry is a relatively low-cost mitigation option under our model specifications. This reflects the current knowledge base of emission reduction opportunities in the land sector. In the future, it is possible that cost-effective emissions reductions could come from technologies that do not yet exist, particularly if incentivised by higher emissions prices.

Figure 10. **Forestry sequestration increases from current levels**
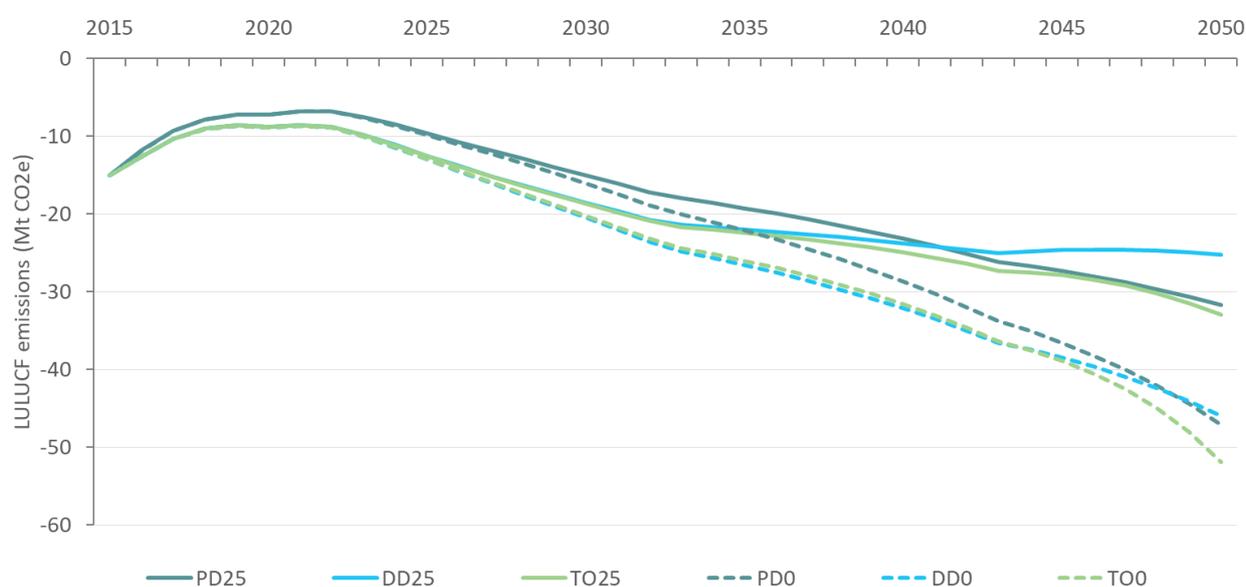
Source: Concept, MOTU, Vivid Economics

Emissions from agriculture decline under all pathways. The smallest relative fall is under the Policy Driven pathways, with emissions falling by 13 per cent in PD25 and 15 per cent in PD0. In

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[13] Note; sequestration in 2015 differs from that reported in the New Zealand National Inventory, due to the use of an averaging approach, and accounting for emissions from harvested wood products.

the other pathways however, agricultural emissions fall by over 20 per cent, with slightly larger reductions under the Techno-optimist pathways (22 per cent in TO25 and 23 per cent in TO0) than the Disruptive pathways (20 per cent in DD25 and 21 per cent in DD0), as shown in Figure 11 below. However, the declines in the Disruptive pathways occur gradually over the period, whereas the Techno-optimist pathways see abrupt change driven by the assumed introduction of a methane vaccine for pastoral agriculture in 2030-31. Differences in agricultural emissions between the 25 $MtCO_2e$ and 0 $MtCO_2e$ targets are minor, with the tighter constraint driving only small changes in overall agricultural activity.

These emissions outcomes imply different patterns of land use change in rural New Zealand. Under all pathways there is a renewed expansion of forestry. The smallest increases occur under the Disruptive pathways, with an additional 1.3 million hectares (ha) under plantation in DD25 and 2.1 million ha under DD0. The largest land use change occurs under the Policy Driven pathways, with 2.0 million ha of additional forestry under PD25 (1.4 million ha of new plantation forest and 0.7 million ha of native forest), and 2.8 million ha under PD0 (1.9 million ha of new plantation forest and 0.9 million ha of new native forest). The Techno-optimist pathways, see forestry increasing by between 1.6 million ha (TO25) and 2.3 million ha (TO0), as shown in Figure 12. Consistent with this, in all pathways, there is an increasing trend of forestry production, with the total forest area harvested 53-63 per cent higher in 2050 than in 2015.[14]

Land used for sheep and beef farming declines under all pathways. It falls from about 8 million ha in 2015, to 6.8 million ha in TO25, 6.6 million ha in DD25 and 6.4 million ha in PD25. Reductions in land use for sheep and beef farming are more pronounced under the 0 $MtCO_2e$ target pathways, with land use declining to 6.4 million ha in TO0, 6.2 million ha in DD0 and 5.9 million ha in PD0. As a corollary, production of sheep and beef (proxied by stock units) declines in all pathways, by between 7 and 16 per cent.[15]

Land used for dairy farming increases under some pathways and falls in others. For instance, the Techno-optimist pathways see dairy land use increase from 2.1 million ha in 2015 to reach 2.3 million ha in 2025 and thereafter remain constant[16]. However dairy land use declines under the other pathways to 2.0 million ha in the Policy Driven pathways and 1.6 million ha in the Disruptive pathways. There is also variation in the change in production of dairy products, which increases by 25 per cent in the Techno-optimist pathways, 7 per cent in the Policy Driven pathways but falls by 11 per cent in the Disruptive pathways.

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[14] These land use changes are all within the realms of previous assessment exercises, that have considered scenarios with forestry expansion of 3 million ha or more. See for instance Hall, P., 2013. Bioenergy options for New Zealand: Key findings from five studies. WIREs Energy and Environment, 2(6), pp.587–601. Hall, P. & Jack, M., 2009. Bio-energy options for NZ: Analysis of Large-Scale Bioenergy from Forestry, Available at: https://www.niwa.co.nz/sites/niwa.co.nz/files/imported/__data/assets/pdf_file/0007/95668/Large-scaleforestry-for-bioenergy.pdf.; Watt, M.S., Palmer, D.J. & Höck, B.K., 2011. Spatial description of potential areas suitable for afforestation within New Zealand and quantification of their productivity under Pinus radiata. New Zealand Journal of Forestry Science, 41, pp.115–129.

[15] The production of stock units does not necessarily result in the same reduction in total production, with, for instance, there being the potential for increased weight of livestock offsetting part of the reduction in stock units

[16] The modelling places a cap on dairy farming land-use from 2025, proxying action to address water quality concerns.

Some of these land changes are spurred by the expansion of horticulture, which is stable at 0.5 million ha under the Techno-optimist pathways but is assumed to double to 1.0 million ha under the Policy Driven pathways and triple to 1.5 million ha under the Disruptive pathways. The associated increase in production has not been quantified, given the variety of horticultural products and uncertainty regarding their future composition.

Better water quality is a co-benefit of reduced nitrous oxide emissions from agricultural soils. Water quality is likely to improve due to reduced nitrogen leaching along all pathways with the potential exception of the Techno-optimist pathways. Nitrous oxide emissions are a proxy for nitrogen leaching, and these emissions decline by almost 10 per cent under the Policy Driven pathways, and by almost 20 percent in the Disruptive pathways. However, in the Techno-optimist pathways these emissions increase marginally.

Figure 11. **Agriculture emissions by pathway**
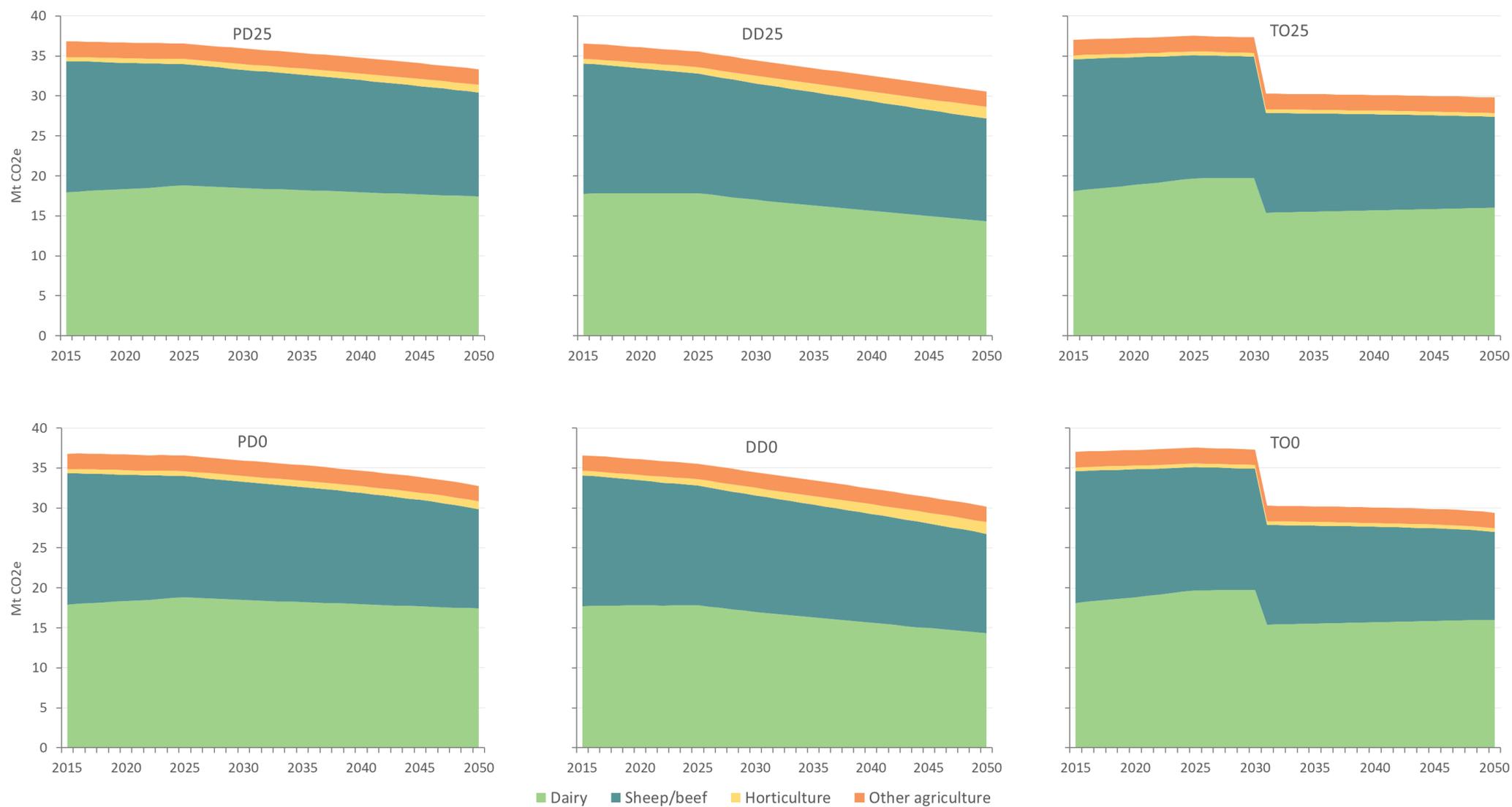
Figure 12. **Agriculture land use by pathway**
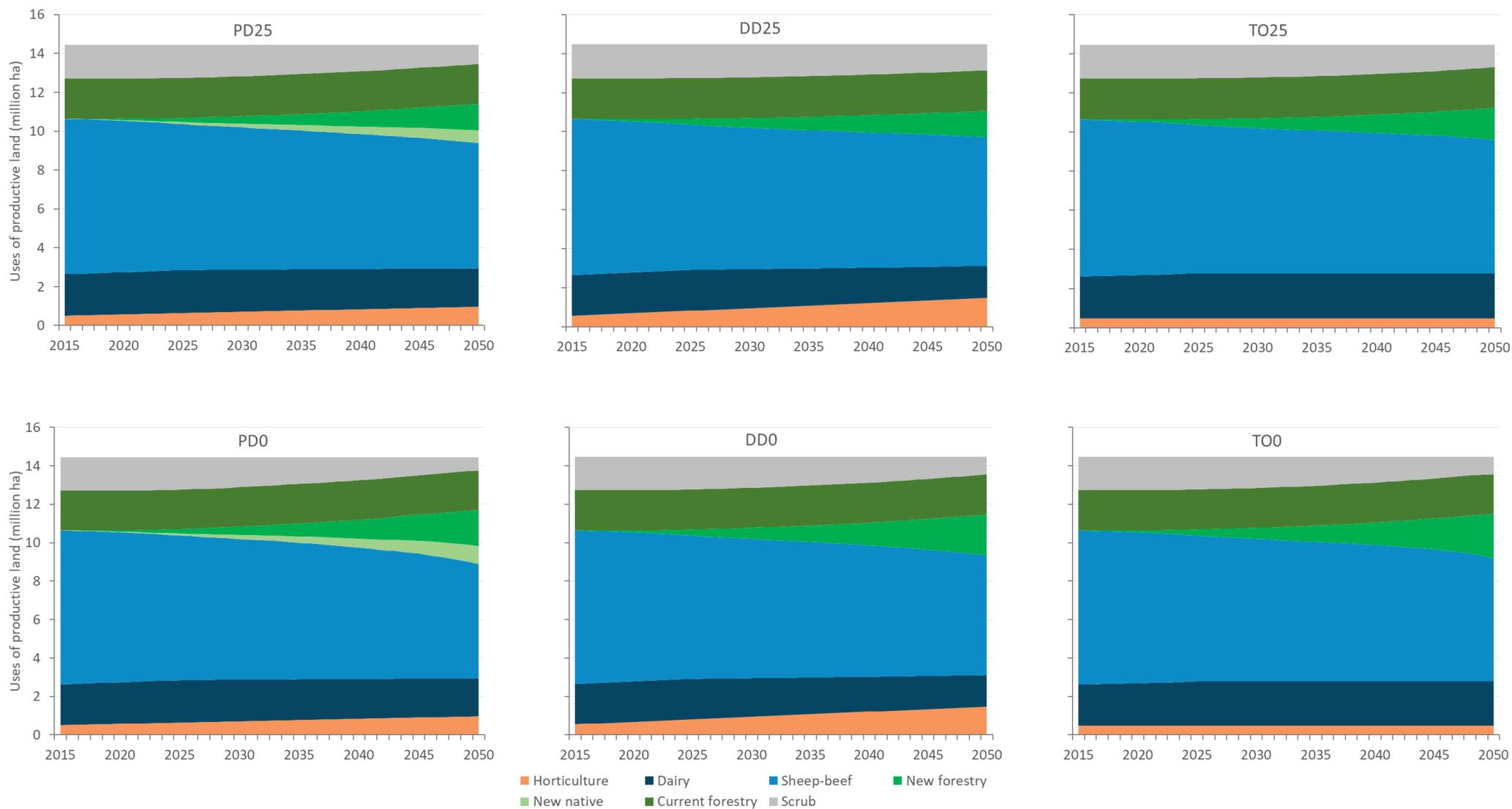
Figure 13. **Output metrics by pathway**

Milk solids (t) — Sheep/beef (stock units) — Forestry harvested (ha)

Source: *Concept, MOTU, Vivid Economics*

Table 3. **Key indicators**

	PD25	DD25	TO25	PD0	DD0	TO0
Overall						
Net emissions (Mt CO2e)						
2015 (est.)	65.1					
2050	25.0	25.0	25.0	3.9	0.0	0.4
2016-50	1,820	1,618	1,777	1,608	1,343	1,544
Gross emissions (Mt CO2e)						
2015 (est.)	80.2					
2050	56.7	50.2	58.0	51.0	45.9	52.4
2016-50	2,442	2,267	2,472	2,367	2,197	2,406
Emissions price (NZ$/tCO2e)						
2050	141.8	75	152.4	200.0	157	250.0
Energy						
Proportion renewable generation[17]						
2015	81%					
2050	94%	95%	96%	95%	95%	97%
Electricity sector emissions (MtCO$_2$e)						
2015	4.9					
2050	3.1	2.7	2.5	2.6	2.6	2.1
Transport						
Vehicle purchase and maintenance costs (NZ$ billion)						
2015 (est.)	10.8					
2050	12.5	13.3	12.1	12.5	13.2	12.0
2016-50	435	471	403	435	469	400

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[17] Runs to date suggests multiple options for the cost-effective supply of low carbon electricity. In these results the majority of new electricity generation was projected to be provided by wind, however estimates of the composition of renewable generation are currently being updated. The final set of results will include estimates of network and wholesale electricity costs for these low carbon systems.

	PD25	DD25	TO25	PD0	DD0	TO0
EV light vehicle share (%)						
2050	63%	79%	37%	65%	80%	39%
Externalities (congestion, and land use) and construction costs (NZ$ billion)						
2015 (est.)	6.5					
2050	9.1	9.4	9.4	9.1	9.4	9.4
2016-50	280	285	285	280	285	285
Externalities, health (NZ$ billion)						
2015 (est.)	5.1					
2050	5.6	5.6	6.3	5.6	5.6	6.2
2016-50	199	197	208	198	196	208
Industry						
Revenue - Iron and Steel (NZ$ billion)						
2050	0.8	0.0	0.7	0.0	0.0	0.0
2016-50	28.3	7.3	27.9	21.0	7.3	24.2
Revenue - Aluminium (NZ$ billion)						
2050	1.0	0.0	1.0	1.0	0.0	1.0
2016-50	35.0	9.0	35.0	35.0	9.0	35.0
Agriculture and forestry						
Output - Dairy milk solids (% change from 2015)						
2030	7%	0%	14%	7%	0%	14%
2050	6%	-11%	25%	7%	-11%	25%
Output - Sheep/Beef stock units (% change from 2015)						
2030	-6%	-7%	-4%	-6%	-7%	-4%
2050	-12%	-13%	-7%	-16%	-15%	-11%
Output - Forestry ha harvested (% change from 2015)						
2030	3%	3%	3%	3%	3%	3%
2050	53%	55%	55%	57%	62%	61%

	PD25	DD25	TO25	PD0	DD0	TO0
Land area (million ha, 2050)[18]						
Dairy	2.0	1.6	2.3	2.0	1.6	2.3
Sheep/beef	6.4	6.6	6.8	5.9	6.2	6.4
Horticulture	1.0	1.5	0.5	1.0	1.5	0.5
Forestry	3.4	3.4	3.7	3.9	4.2	4.4
New native	0.7	0.0	0.0	1.0	0.0	0.0
Scrub	1.0	1.3	1.1	0.7	0.9	0.9
Emissions from agricultural soils (% change from 2015)						
2030	-1%	-6%	3%	-1%	-6%	3%
2050	-8%	-18%	4%	-9%	-19%	3%

Source: *Concept, Motu, Vivid Economics*

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[18] 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

5. Discussion

The results outlined above reveal a New Zealand with a very different economy and emissions profile to today. Given the scope and scale of potential changes within and between the pathways, this section considers in more detail some of the key findings and potential implications from these initial modelling results.

5.1 Substantial progress can be made to decarbonising New Zealand's economy at prices comparable to other developed countries

The initial findings suggest that New Zealand is likely to be able to decarbonise its economy at a cost comparable to that expected in the rest of the developed world. Under a 25 MtCO$_2$e target, the domestic emissions prices required to put New Zealand on track to a net zero emissions economy are below Paris consistent global emissions prices until well after 2035, and below or towards the lower bounds of anticipated Paris Agreement consistent emissions prices in 2050 (see Figure 14 below). This reflects a confluence of factors, most notably the potential for reasonably significant increases in afforestation and its low-emissions intensity grid facilitating the cost-effective uptake of electric vehicles.

Figure 14.   **Emissions prices to achieve net zero consistent emissions**
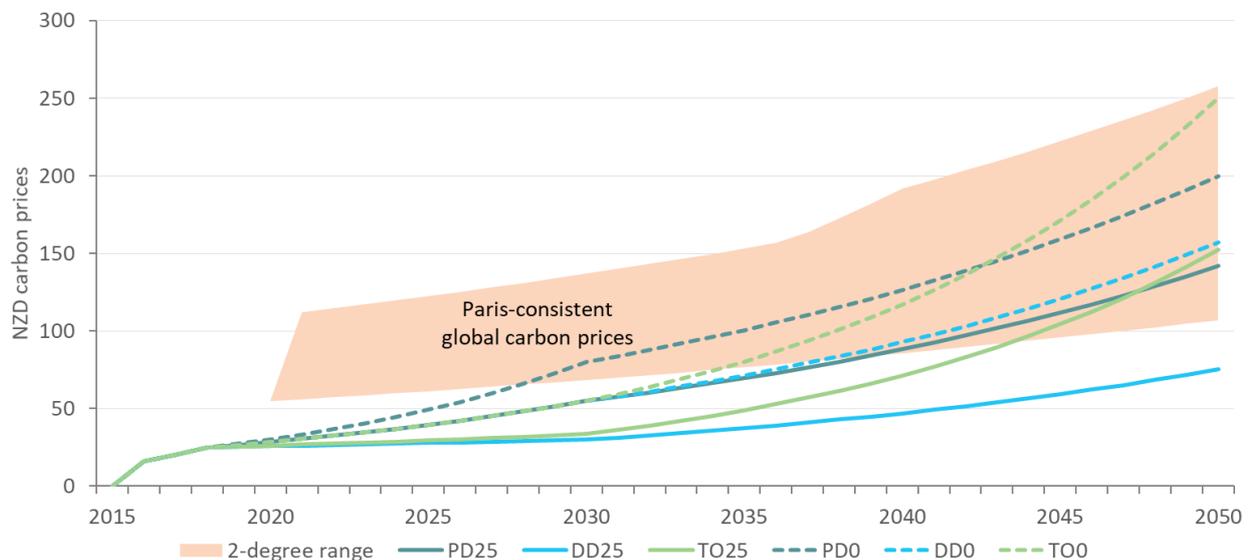
Note: *Paris-consistent global emissions prices are based on the range of estimates developed by the Carbon Pricing Leadership Coalition and under the IEA's Sustainable Development Scenario. These estimates do not extend to 2050, as such we have extended these price series at the lower of their implied real growth rate or 3 per cent per annum, to approximate the Hotelling scarcity price-path. Prices are translated to NZD using an exchange rate of 0.73 USD/NZD. The Paris Agreement has the objective of limiting global temperature rise to well below 2ºC and to pursue efforts to limit the temperature increase to 1.5ºC, the price trajectories utilised are expected to limit global temperature rise to less than 2ºC.*

This is particularly evident under the Disruptive pathway, which achieves both the lowest emissions prices and the lowest cumulative emissions over the 2016-50 period. In this case technological developments and structural change early in the modelling period enable emissions to be constrained in the 2020's and 2030's, reducing the required emissions reductions after this period. The emissions prices needed are particularly low in the DD25 pathway, where they remain far below the anticipated envelope of Paris-consistent emissions prices throughout the period.

When moving to the more stringent 0 MtCO$_2$e target, the prices for all three pathways are toward the middle of the envelope of Paris-consistent emissions prices for PD0 and DD0, and toward the upper bound of anticipated prices for TO0. In the pathway with the highest emissions price under this constraint, the Techno-optimist pathway, emission prices reach around NZD250/tCO$_2$e in 2050.

5.2 There are several features common to all pathways

A clear majority of net emissions reductions in all three pathways are sourced from agriculture, forestry, and transport; this implies that any New Zealand decarbonisation strategy should focus on these opportunities.

Forestry provides a significant proportion of the net emissions reductions required. Forest sequestration provides 25-45 per cent of the net emissions reductions required to meet the 25 MtCO$_2$e target and 47-57 per cent of net emissions reductions required to meet the 0 MtCO$_2$e target. This implies that a concerted expansion of the forestry sector is likely required to put New Zealand on a path consistent with net zero emissions by the middle of the century.

Agriculture is also a significant source of mitigation. In all pathways, there is a reduction in pastoral agriculture, with sheep and beef farming, being outcompeted by alternate uses. In the techno-optimist pathway, the successful development of a methane vaccine reduces emissions intensity and limits, but does not fully offset, the need for land-use change. In the 25 MtCO$_2$e target pathways, reductions in emissions from agriculture are responsible for 13-22 per cent of total net emissions reduction, and 9-14 per cent of emissions reductions in the 0 MtCO$_2$e target pathways.

Transport is the major driver of emissions reductions in the energy sector. The pace of technological development and uptake is of primary importance for the transport sector. In the 25 MtCO$_2$e target pathways, reductions in emissions from transport, primarily electrification of the transport fleet, are responsible for 8-24 per cent of total net emissions reduction, and 6-16 per cent of emissions reductions in the 0 MtCO$_2$e target pathways. The expansion of EVs in turn increase demand for further electricity generation which, the modelling suggests, will be cost effectively met through additional renewable generation. There is relatively little difference in the outcomes for the energy sector between the 25 MtCO$_2$e and 0 MtCO$_2$e targets, with the increased emissions price in the latter pathways only driving a marginal increase in mitigation.

Other sources deliver 25-31 per cent of net emissions reductions. This is mainly achieved by reducing emissions from direct energy use in agriculture (for instance, for heat and motive power

such as tractors) and process heat for food processing, alongside reduced emissions from refrigeration and from the closure of iron and steel – particularly in the 0 MtCO₂e target pathways.

5.3 But differences between strategies merit further consideration

While there is much that is common to the different pathways, the differences reveal important choices that New Zealand can take on the relative contribution made by different sectors and options for reducing the country's emissions. Figure 15 below shows how New Zealand's emission reduction effort can be split across five main sectors/options, and the relative weight that the different pathways place on each of these. These options are:

  – **Electric vehicles**, driving emissions reductions in the transport sector.
  – **Reductions in emissions intensity of agriculture**, driven primarily by the potential introduction of a methane vaccine and/or inhibitor in pastoral agricultural systems.
  – **Structural change in agriculture,** moving from highly emissions intensive farming structure to forestry, or less intensive agricultural options, such as crops or horticulture.
  – **Forest sector sequestration,** with plantation forestry increasing carbon stock and sequestering emissions.
  – **Other options**, such as improving industrial emissions intensity.

Figure 15. **Forestry sequestration is of central importance for achieving a net zero greenhouse gas target**
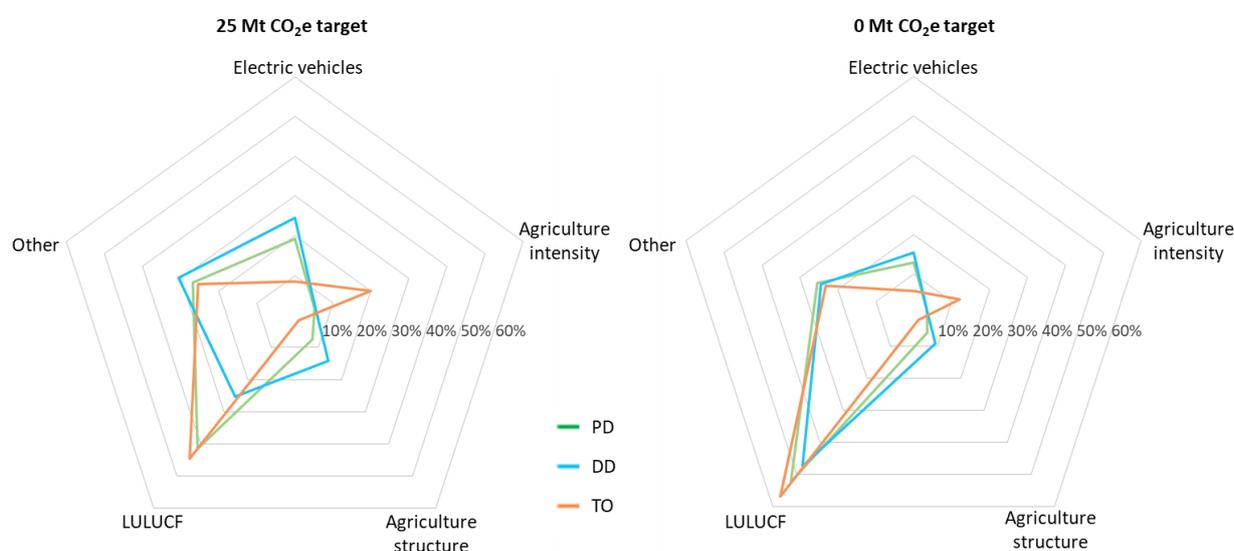
Note: *Diagram shows proportion of mitigation from 2015 to 2050 by key attribute*

Under the 25Mt CO₂e targets, the Policy Driven and Techno-optimist pathways rely most heavily on forestry, which means that less mitigation is required from each of the other four sources. The Disruptive pathway, by contrast, relies more on the expansion of electric vehicles (including in heavy vehicles) and structural change in other sectors of the economy. The Techno-optimist pathway draws much more of its emission reductions from reductions in agriculture emissions intensity, and much less from changes in agriculture structure.

However, under all 0 MtCO₂e pathways, sequestration from forestry dominates. In these cases, it provides about half of the required reduction in net emissions. In other words, in moving from a 25 MtCO₂e target to a 0 MtCO₂e target, the modelling suggests that much of the 'heavy-lifting' would be done through expansion of the forestry sector.

Social and political preferences will influence the attractiveness of drawing on these different sources of mitigation opportunity. In addition, however, the next phase of modelling work will help identify how robust the pathways (and hence their implied distribution of emission-reduction costs) are, to uncertain, external events.

5.4 Transitioning from forest sequestration may prove challenging

While afforestation provides plenty of scope for reducing emissions in the short term, there could still be challenges in the longer term. Figure 16 below, shows the gross emissions (i.e. before the effect of LULUCF emissions) in each of the three pathways. In each case, gross emissions in 2050 are only 28-43 per cent lower than in 2015.

Figure 16.   **Under all pathways New Zealand's gross emissions fall by less than 50 per cent**
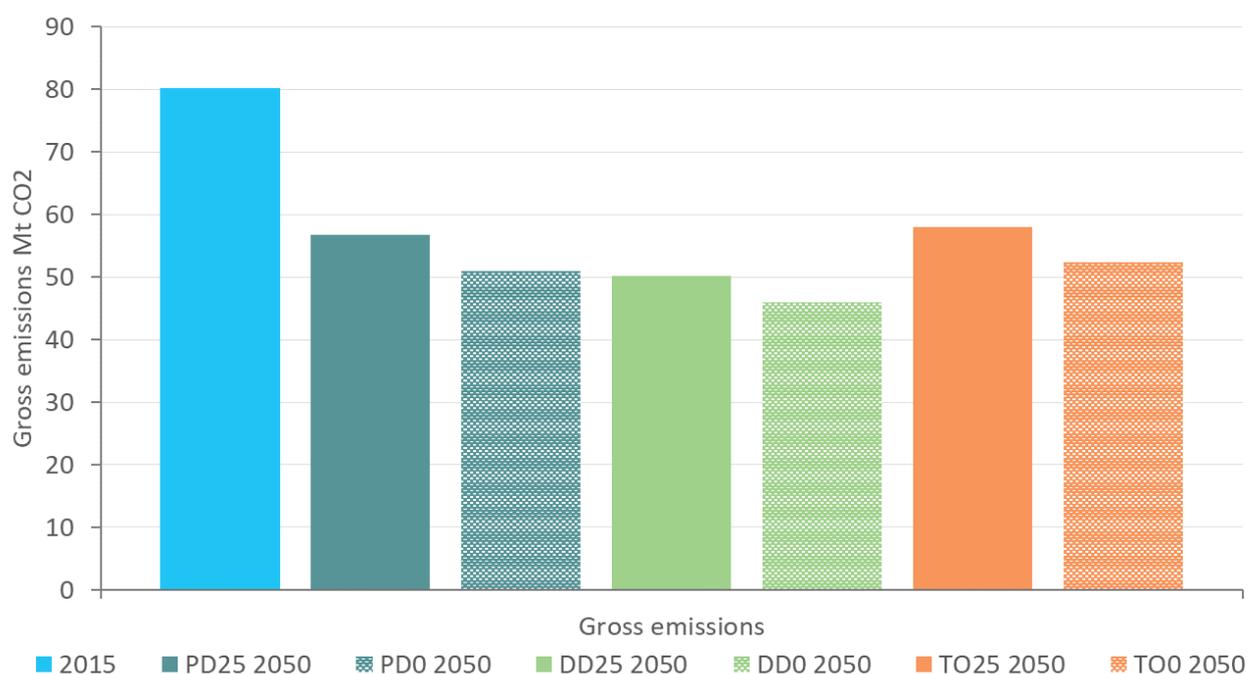
Source: *Concept, MOTU, Vivid Economics*

To continue to reduce emissions beyond 2050 (or to stay at net zero emissions beyond this date), New Zealand would either need to find ways of reducing these emissions, or to continue to sequester emissions from forestry. The latter could involve a combination of further transition to forestry in land use patterns – which could be facilitated by technological breakthroughs, such

as synthetic meats – or by transitioning from plantation forestry to permanent forestry. At the emissions prices suggested in this modelling, there is likely to be significant movement from harvested forestry to permanent carbon forestry, a dynamic not captured by our modelling.

5.5 No pathway clearly outperforms across all indicators

Each pathway has distinctive attributes. Given different assumptions across pathways these attributes should be considered in terms of the implications for managing economic and social change, rather than used to identify *preferred* pathways.

Key trade-offs for each pathway include:
- The **Policy Driven** pathway requires higher emissions prices in the short term to support constrain emissions, but then sees these prices grow at a slower rate than those of the techno-optimist pathway to 2050. However, it still features the highest cumulative emissions. It sees a large expansion in forestry production and moderate increases in dairy production but large reductions in output from sheep and beef. At the same time, policy to expand native forestry may bring biodiversity and other environmental benefits and provide sequestration over long time periods. Support for public transport reduces externalities but this needs to be balanced against increased government costs incurred.
- The **Disruptive** pathway has the lowest cumulative emissions, lowest gross emissions, and lowest emissions prices of all pathways. However, it also is typified by lost revenues from the closure of iron and steel and aluminium in 2025.[19] It has the lowest 2050 electricity network costs and highest EV penetration rate, but also the highest vehicle capital and maintenance costs. This pathway is the only one which sees a reduction in dairy production, but it also sees a trebling in land dedicated to horticulture and a large expansion in forestry.
- The **Techno-optimist** pathway results in the highest emissions price by 2050, but also avoids a degree of disruption in the process. It has the largest increases in dairy production, and smallest falls in sheep and beef production of all pathways, but this means it is also likely to deliver the worst outcome of the pathways for water quality. The pathway does however maintain the highest cumulative revenue from iron and steel and aluminium production, even though iron and steel manufacturing closing under the tighter emissions constraint. While the rate of expansion in EVs is low, this is reflected in lower vehicle capital and maintenance costs but also higher fuel costs.

In addition, the choice of a less or more stringent target brings its own trade-offs. This modelling examines the impact of less and more stringent targets while holding other assumptions constant. As expected, this shows that a tighter target results in higher emissions prices and the potential for greater structural change. However, the appropriate analysis of a targets and contribution to global climate does not simply relate to the cost of mitigation, but also to cost incurred from climate change and an assessment of New Zealand's appropriate share of action as part of a global response. Further, the economic interactions modelled do not account for the potential economic

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[19] As noted above, this is an imperfect proxy, with other indicators such as gross value added or employment levels provided better indications of potential economic and distributional impacts.

advantages stemming from early action, for instance innovation and the development of new technologies and processes.

The next stage of this modelling process will seek to provide a richer understanding of the potential trade-offs involved from adopting different strategies under uncertainty. The pathways set out above show how strategies developed in response to expectations regarding the future state of the world perform when these expectations prove correct. However, our expectations regarding the future are often incorrect, which is often also reflected in the performance of strategies deviating from our expectations. The next stage of the modelling will consider how scenarios perform under six different realisations of uncertain future states of the world. These uncertainty variants represent different ways in which the exogenous environment may evolve as New Zealand develops its decarbonisation strategy.

Uncertainty variants will include combinations of different prices and technological developments to provide insights as to how scenarios perform in transitioning to a very low emissions economy. The uncertainties that will be altered between variants, include the international emissions price, fossil fuel and commodity prices across energy, industry, agriculture and forestry, and technological developments such as the rate of decline in EV costs or the availability of a vaccine to reduce methane emissions in livestock. In doing so these variants will approximate worlds featuring different levels and compositions of technological change and degrees of international action, to seek to identify those scenarios that are robust, in delivering relatively good outcomes across multiple states of the world; and those that are fragile, which are associated with significant costs under certain circumstances.

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

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[20]; 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 a 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

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[20] 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 – that is, 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 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. These features are outlined in Figure 17 below.

Figure 17. **Schematic representation of the LURNZ model**
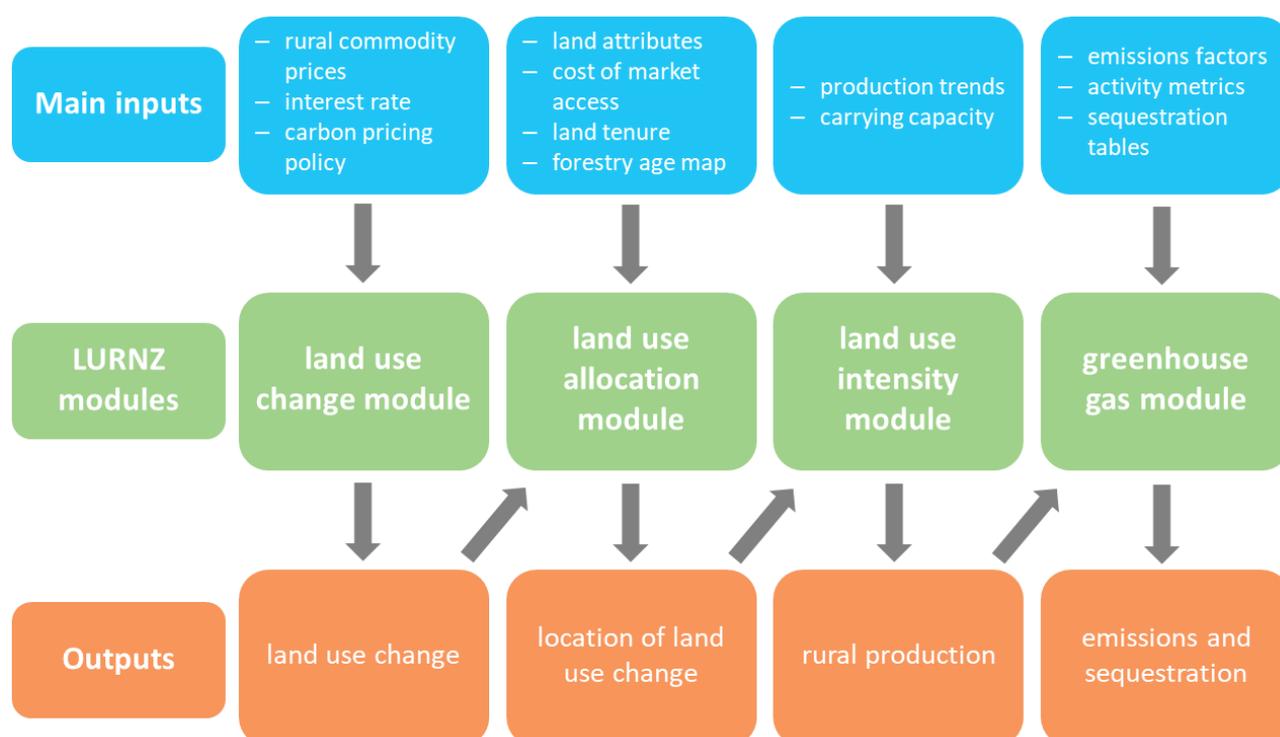
Source: Concept, Motu, Vivid Economics

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).

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.[21,22]

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 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 also be interpreted as other policies that have 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 research and development.

For dairy and sheep-beef, the effect of emissions prices on commodity prices is determined by calculating greenhouse gas emissions (in CO_2e) 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).[23]

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, there are some factors that reduce the magnitude of this: these include the discounting of returns

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[21] 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).

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[22] 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.

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 are 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 because 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).[24]

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[24] 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 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. To approximate production in plantation forestry, we calculate the area harvested in each year.[25]

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 accounting rules that lead to large fluctuations over time in net emissions depending on harvest patterns. 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 18 below.

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[25] 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 18. **Averaging reduces variability of emissions and sequestration over time**
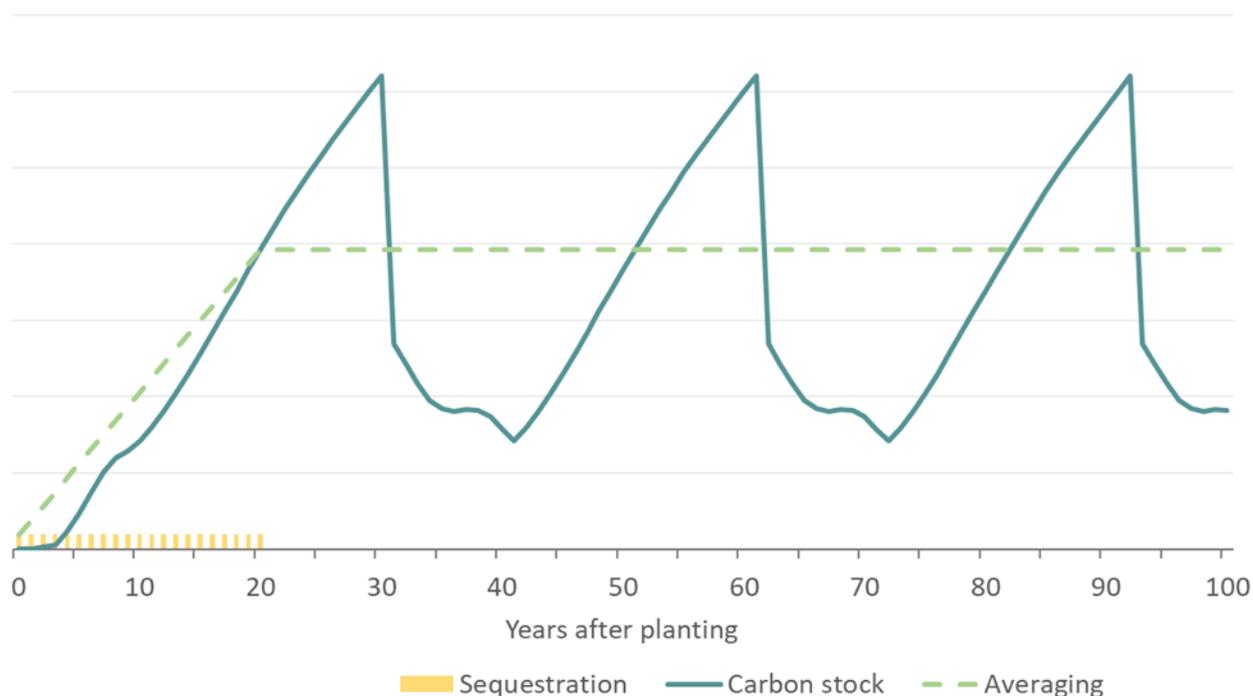
Note: *Graph is indicative only, note sequestration counted under an averaging approach includes sequestration from increased carbon stock from harvested wood products which isn't included in carbon stock in the graph*

The average level of carbon stock is reached 21 years after planting. A linear trend for carbon accumulation up to that point is applied. Based on the *pinus radiata* sequestration profile in the look-up tables underlying the National Inventory, this corresponds to an annual accumulation of 31.83 tCO$_2$ per hectare over the first 21 years. This is the amount of sequestration we associate with each hectare of new exotic forest land for 21 years after planting.

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 area between 1991 and 2012. 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 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

effects of carbon forestry would be more pronounced in the second half of the century which is beyond our simulation horizon), as such, LURNZ projections for the sector are conservative.[26]

On the other hand, the controls applied to forestry land-use changes in the allocation algorithm (described above) mean that LURNZ projects zero deforestation if overall forestry area increases. Emissions associated with deforestation are currently estimated at around 4 $MtCO_2e$ per year. As LURNZ cannot model this component, we expect to underestimate emissions from the sector by 4 $MtCO_2e$ under current conditions. This bias is reduced with higher carbon prices, and is not expected to have a major effect on pathway results.[27]

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 Policy Driven pathway involves a growth of 500,000 hectares in horticulture area to 2050, and the Disruptive pathway involves 1,000,000 hectares expansion over the same period. These rates of expansion are significantly higher than observed in historical trends, but they are considered feasible by experts in horticulture.

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[26] 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.

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[27] Deforestation is highly sensitive to emissions prices. A survey of large-plantation owners suggests that deforestation decreases at a emissions price of about $7/tonne and is likely to stop almost completely once the emissions price reaches only $15/tonne, see Manley, 2016, *Afforestation responses to carbon price changes and market certainties.*

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.[28]

Constraint on dairy expansion
The pathways constrain the expansion of dairy farming, with no new land converted to dairying beyond 2025. This constraint reflects an anticipation of councils setting water quality limits in their regions.[29]

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 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 pathway, 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 considering 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

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[28] 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.

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[29] 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.

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.

Methane vaccine
In the Techno-optimist pathway 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 per cent for dairy and by 20 per cent 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.

Refinements planned for phase two of modelling
We have identified some areas where the modelling completed for the interim report will be updated for the final report. Below is a brief discussion of upcoming changes and, where known, their expected effects.

Projected emissions efficiency improvements in pastoral agriculture currently affect emissions only, but not the incentives for land-use change. Similar to the modelling of the methane vaccine, the effect of efficiency improvements can also be incorporated in land-use incentives by making an appropriate adjustment to commodity prices. This adjustment will be completed for the final report – the effect of this change on simulated land use and emissions has not yet been fully assessed but are likely to be small relatively to total emissions (initial estimates suggest an impact of about 1 $MtCO_2e$ in 2050).

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 19 below.

Figure 19.   **Schematic representation of the ENZ model**

Main inputs
- projections of emissions prices, fossil fuel prices, technology costs and population
- assumptions regarding exogenous closure of electricity generation or industry capacity
- allocation approach under NZ ETS
- policies regarding public transport and vehicle scrappage

ENZ modules

Industry
- industry remain/exit for key sectors
- heat demand from agriculture & forestry (drawing on LURNZ)

Consumer heating
- space & water heating
- other industrial heat
- electrification and/or energy efficiency

Transport
- service demand
- transport mode and technology (electric & ICE, public & private transport)

Electricity
- demand
- generation mix

Fossil production
- production & refining of fossil fuel

Waste & misc.

Outputs

Electricity demand, generation and emissions

Fossil production, consumption and emissions

Other emissions (waste, industrial processes)

Source: Concept, Motu, Vivid Economics

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.

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[30].

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

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 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-river31 hydro)

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[31] 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.

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-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.

<u>Which type of renewables are likely to be least cost</u>
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.

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