Net zero in New Zealand

Scenarios to achieve domestic emissions neutrality in the second half of the century

Summary report

Report prepared for GLOBE-NZ

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The summary report and supporting technical report can be downloaded from:
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Executive summary

While there may be bumps in the road, the direction of travel is clear: the world has committed to a low-emissions future. The Paris Agreement, which New Zealand ratified on 4 October 2016, and which came into force on 4 November 2016, commits the world to *holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels*. The Agreement also commits the world to the global peaking of emissions as soon as possible and to *'achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century'* – the so-called net zero goal. In looking to meet these goals, developed countries are expected to continue to take the lead in reducing emissions, reflecting the principle of equity and common but differentiated responsibilities and respective capabilities. The commitment among the global community to these goals remains strong despite recent events in the US; indeed it has been reaffirmed by many. This reaffirmation reflects the risks and damages that unaddressed climate change poses, not least to New Zealand.

In meeting this challenge, New Zealand is distinctive in at least three respects: its significantly decarbonised energy sector; its large share of difficult-to-reduce land sector emissions; and its large forestry sector. Elsewhere in the world, more focus has been devoted to reducing emissions from the electricity sector than from any other sector. Huge efforts and costs are now beginning to translate into progress. But for New Zealand, these challenges are of less significance. Its power sector consists primarily of hydroelectric and geothermal resources, providing firm, reliable capacity. Even with the challenge of decarbonising other parts of the energy sector (transport fuels, heat), the resulting relatively low-carbon energy mix provides the country with a considerable competitive advantage in a world that is placing increasing constraints on emissions. Yet, at the same time, the importance of the pastoral agriculture sector to the economy and social fabric of the country creates a huge challenge, although one that is laced with opportunity. Biological emissions from agriculture account for almost half of New Zealand's gross emissions[1], a higher proportion than in any other developed country. While other developed countries may choose to not prioritise reducing these emissions in the short term, following suit would have important repercussions for New Zealand in meeting future targets. Finally, New Zealand's climate and geography mean that forestry makes a significant contribution to the economy. This provides large carbon-sequestration potential: the sector currently sequesters about 30 per cent of gross emissions (New Zealand Ministry for the Environment 2016). However, it also brings challenges as, compared with other countries, much of New Zealand's forestry assets are managed in the private sector and are therefore subject to commercial pressures.

1 Gross emissions exclude net emissions or removals from the forestry sector; net emissions accounting includes the forestry sector. A simplified Kyoto-style accounting approach is adopted for this sector in this report.

This report, commissioned by GLOBE-NZ – a cross-party group of 35 members of the New Zealand Parliament – is one of the first attempts to apply scenario analysis across the New Zealand economy, covering both land and energy, to help illuminate long-term low-emission pathways. While the goal of the Paris Agreement is clear, how different countries might contribute to its achievement in the medium term, and the associated economic implications, are much less so. Scenario planning can play a key role. The role of scenarios is not to make predictions of what the future will or should be. Rather, they paint internally consistent pictures of how the future might turn out, and use the similarities and differences between scenarios to allow decision-makers to help identify robust strategies, key trade-offs and possible perverse outcomes. New Zealand has a rich history in using scenario planning to inform policy and help businesses and society prepare for an uncertain future.

The scenarios involve a significant departure from the technologies and practices commonplace in New Zealand today; yet within this context, they span a range of different options. At the least ambitious end of the range, while still requiring the adoption of new technologies, especially in the transport and energy sectors, the likely percentage reduction in emissions by 2050 is lower than has been committed to by many other countries and will be insufficient to place the country on a trajectory towards emissions-neutrality in the second half of the century. At the other end of the range, the scenario analysis shows how it might be possible for New Zealand to reach net zero emissions domestically by 2050, implying a greater percentage reduction in emissions than virtually any other country has committed to.

All scenarios envisage the country exploiting abundant opportunities to pursue emission reductions that are either competitive with, or almost competitive with, more emissions-intensive alternatives. In the energy sector, these opportunities, highlighted in a burgeoning international evidence base on so-called 'deep decarbonisation' opportunities, include energy efficiency, further decarbonisation of electricity generation, and the electrification of the transport fleet and of low-grade heat. There are also some similar opportunities in the agriculture sector including improving low-performing farms, breeding lower-emissions livestock and taking advantage of new feeds. In combination, these opportunities are attractive to implement, especially if the rest of the world extends its decarbonisation efforts and drives technologies further down the cost curve. As well as providing low-cost (in the terms used in this report) ways of reducing emissions, they can also improve the health of New Zealand's citizens, help reduce energy poverty, enhance mobility, improve water quality, and make New Zealand an attractive location for the low-emissions industries of the future.

In our first scenario – Off Track New Zealand – the country largely focuses on exploiting these low-cost emission-reduction opportunities, but does not significantly alter its land-use patterns. By 2050, there is significant change in the energy sector, with renewable power generation growing by 75 per cent, 85 per cent of the light-duty passenger vehicle fleet electrified, as well as significant low-temperature heat being provided by electricity. In the agriculture sector, farm- and animal-based efficiency improvements such as targeted breeding, new feeding regimes and nitrogen and methane inhibitors are accelerated, and process improvements like precision agriculture further reduce emissions intensity by reducing fertiliser use. However, there are only modest changes in land-use patterns: forestry expands by around 0.5 million hectares while livestock numbers remain at current levels. This results in net emission reductions of around 10–25 per cent on 2014 levels by 2050,[2] equivalent to a 0.3–0.8 per cent reduction each year. This would not leave the country on the path to domestic net zero emissions. In other words, it is not sufficiently ambitious to allow the domestic economy to mirror the global goal that has been set.

The extent to which domestic abatement outcomes can move beyond the Off Track scenario depends on rates of technological progress and patterns of land use. The most important areas where technological progress could deliver further emission reductions is through facilitating the widespread availability of low-cost vaccines to reduce agricultural methane emissions and developments that allow greater electrification of transport and heat at manageable cost. These improvements could come to pass as a result of supportive research, development and demonstration programmes, both globally and in New Zealand. With regard to land use, the key strategic choice concerns whether to use the land in a less emissions-intensive way, taking account of trade-offs such as the impact of alternative land uses on water quality and on rural communities.

To explore these opportunities, two further scenarios vary the degree of technological improvement and land-use patterns to generate more rapid emission reductions of around 3 per cent per annum domestically. If this rate of reduction can be sustained – a challenge that requires the pursuit of ongoing emission reductions beyond 2050 – these scenarios put New Zealand on the path to emissions neutrality in the second half of the century. As such, they are expected to be consistent with New Zealand reducing its domestic emissions in line with what would be required globally to meet the 2°C temperature goal of the Paris Agreement. Although the level of emissions reduction is similar between Resourceful New Zealand and Innovative New Zealand, they demonstrate the possibility of using different strategies to reach this goal – either a smaller agriculture sector and more technology in the case of Innovative, or a larger forestry sector in the case of Resourceful:

1. *Innovative New Zealand.* Under this scenario, New Zealand further reduces the emissions intensity of its economic activity through technological advances such as cost reductions in electric vehicles for freight; electric heating technologies for high temperature applications; and a vaccine to reduce methane emissions from pastoral agriculture. This is accompanied by a structural shift away from pastoral agriculture – with animal numbers around 20–35 per cent lower than today – to less emissions-intensive activity. New Zealand instead supports a diverse range of land uses including horticulture and crops, alongside extensive afforestation covering an

2 The range of emission reductions reported here and in other scenarios reflects the uncertainty over the future economic prospects of emissions-intensive industries such as steel and aluminium manufacturing and refining. We have not included scheduled industry closure as an explicit emission-reduction strategy. However, the potential for industry closure pervades all scenarios and so we report ranges in emissions outcomes to reflect this possibility (that is, closure of iron and steel refineries and aluminium facilities forms the lower-emissions bound for each scenario). In addition, throughout, percentage reductions of emissions are reported on a net–net basis (comparing net emissions in 2014 with net emissions in 2050), on the basis that this represents the clearest metric of progress towards the net zero goal.

additional 1 million hectares of land by 2050. This shift in land-use patterns away from pastoral agriculture delivers lower emissions, a robust agricultural sector and continued economic growth. However, it relies on technology breakthroughs in, for example, high-grade heat and non-passenger transport, as well as additional new technologies in the agriculture sector. Under this scenario, our analysis suggests that New Zealand's net emissions could reach 12–17 MtCO_2-e by 2050 (a 70–80 per cent reduction compared with current levels, implying an annual reduction of 3.3–4.3 per cent), with long-lived greenhouse gas emissions below zero in 2050.

2. *Resourceful New Zealand.* In this scenario, decarbonisation of the energy sector beyond that in Off Track is not pursued because global technological development does not progress rapidly. In this case, significant afforestation is required to offset residual emissions, and plantation forests expand by 1.6 million hectares by 2050. This would substantially reduce emissions, and provide opportunities in a significantly enhanced forest products industry. However, changed land uses may require a difficult transition for rural economies, as well as represent a lost opportunity to reintroduce native habitat. Under this scenario, our analysis suggests that New Zealand's net emissions could reach 14–21 MtCO_2-e by 2050 (a 65–75 per cent reduction compared with current levels, or an annual reduction of 2.8–3.9 per cent). As with Innovative New Zealand, long-lived greenhouse gas emissions are below zero by 2050.

Table 1 provides a detailed breakdown of the three scenarios while Figure 1 shows this graphically.

Figure 2 further characterises the Off Track, Innovative and Resourceful scenarios in terms of the different levels of technological improvement and patterns of land use. If New Zealand were not to pursue a low-emissions future, it would remain in the bottom left-hand position on this chart, which corresponds with the highest emissions levels. Moving up the vertical axis in the direction of technological improvement leads to an Off Track New Zealand, where the land-use patterns are largely the same as at present, but where technological change allows, for instance, the widespread penetration of passenger electric vehicles. However, this is not consistent with a domestic net zero emissions economy in the second half of the twenty-first century. By contrast, net emissions in 2050 in Resourceful and Innovative New Zealand, towards the top right-hand corner of the figure, are sufficiently low to be on track for a net zero domestic emissions future. The figure also shows that a New Zealand in the top left-hand corner would benefit from technological efficiency improvements in the energy and land sectors, but the maintenance of current land-use patterns means that it would not be on the path to net zero domestic emissions.

This analysis has important implications for land-use planning in New Zealand. First, while significant emission reductions can be achieved in the energy sector, a net zero domestic emissions target requires changes to the activities which generate value from land. Higher-value-added and lower-emissions industries such as horticulture and crops could be increased to sustain New Zealand's economic growth. Second, while it is

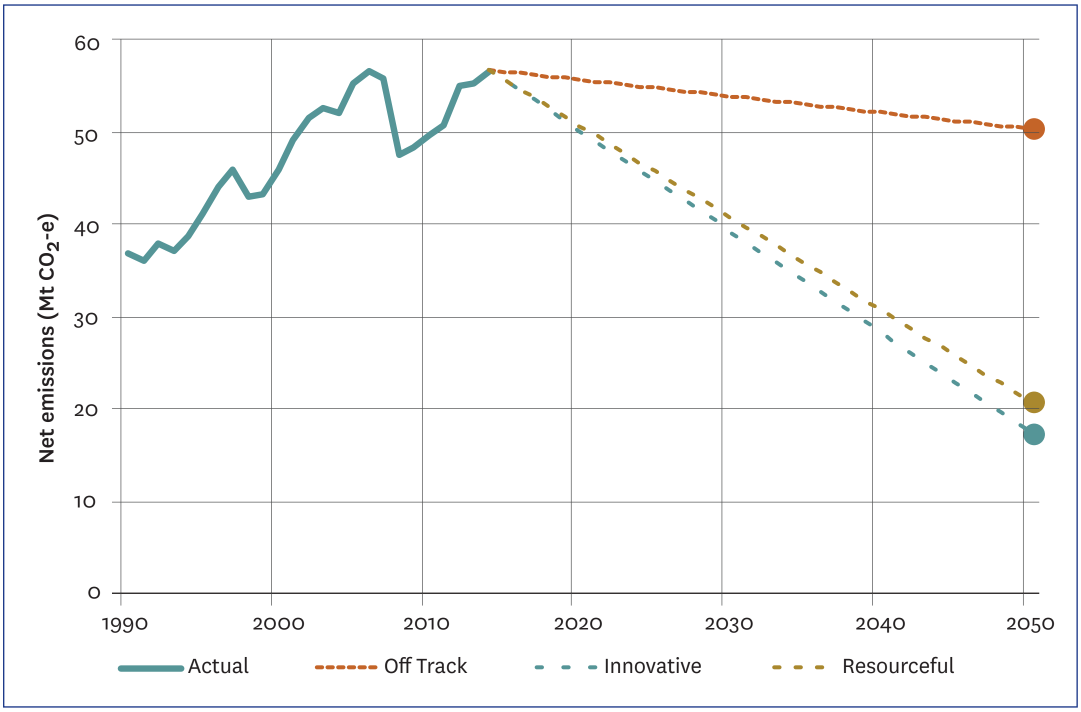
Table 1 All three scenarios result in net emission reductions compared with 2014 ($MtCO_2$-e)

		1990	2014	Off Track 2050	Innovative 2050	Resourceful 2050
Energy	Electricity	3.5	4.2	3.3	0.8	3.3
	Transport	8.8	14.1	6.1	4.3	6.1
	Other fossil fuels	10.2	11.8	8.3	5.3	8.3
	Sub-total	23.8	32.1	20.5	12.7	20.6
Industry	Mineral	0.6	0.8	1.1	1.1	1.1
	Chemical	0.2	0.4	0.3	0.3	0.3
	Metal	2.7	2.3	2.5	2.4	2.5
	HFCs and solvents	0.1	1.6	0.3	0.3	0.3
	Sub-total	3.6	5.2	4.2	4.1	4.2
Agriculture	Enteric fermentation	26.3	28.6	22.6	14.3	18.7
	Manure	0.7	1.3	1.1	0.9	1.0
	Soils, liming, urea	7.3	9.7	9.5	9.5	8.8
	Other agriculture	0.0	0.0	0.0	0.0	0.0
	Sub-total	34.4	39.6	33.2	24.7	28.5
Waste	Land	3.8	3.7	3.3	2.2	3.3
	Water	0.3	0.4	0.5	0.5	0.5
	Sub-total	4.1	4.1	3.9	2.8	3.9
Gross		65.8	81.0	61.8	44.3	57.2
Land use, land-use change and forestry (LULUCF) (average 2040–59)		-28.9	-24.4	-11.5	-26.9	-36.4
Net		36.9	56.7	50.3	17.5	20.8
Of which long-lived greenhouse gases (GHGs) (CO_2 and N_2O)		3.7	20.2	21.9	-1.1	-3.6
Low industry sensitivity		n/a	n/a	-7.0	-5.5	-7.0
Net (low industry)		36.9	56.7	43.4	12.0	13.8

Source: Vivid Economics, 1990 and 2014 emissions from New Zealand Ministry for the Environment (2016).

Note: The low industry emissions sensitivity relates to a situation in which there is closure of oil refineries, aluminium and steel manufacturing plant. Emissions accounting seeks to mirror that used in the national inventory to the greatest extent possible, however simplifications have been adopted, particularly regarding emissions from land-use, land-use change and forestry, given the complexity of accounting for emissions from these sources. Figures reported in this table for 1990 and 2014 reflect the national inventory. The 2050 projections represent an annual average level of emissions from 2040-59 because of large variance of in-year estimates. We calculate these using an averaging approach for calculating forestry sequestration and assume that all land currently forested remains forested and that it has reached its long-term average carbon stock by 2050. We also assume no sequestration from improved forest management of native or plantation forests planted before 2015. The implication is that we only report net average annual carbon stock changes in 2050 (2040-59) from new forests planted after 2014.

Figure 1. Changed land-use patterns, such as in Resourceful or Innovative New Zealand, are required to be on the path to net zero domestic emissions



Source: Vivid Economics

Notes: Emission reductions are reported on a net-to-net basis, compared to 2014 – the most recent data for emissions – as this represents, in the authors' view, the most transparent and easy-to-understand metric for assessing the extent of change from 2014 emissions and progress towards a net zero goal. An alternative approach of gross-to-net is adopted in the Kyoto Protocol and Paris Agreement accounting rules for New Zealand's emission reduction target.

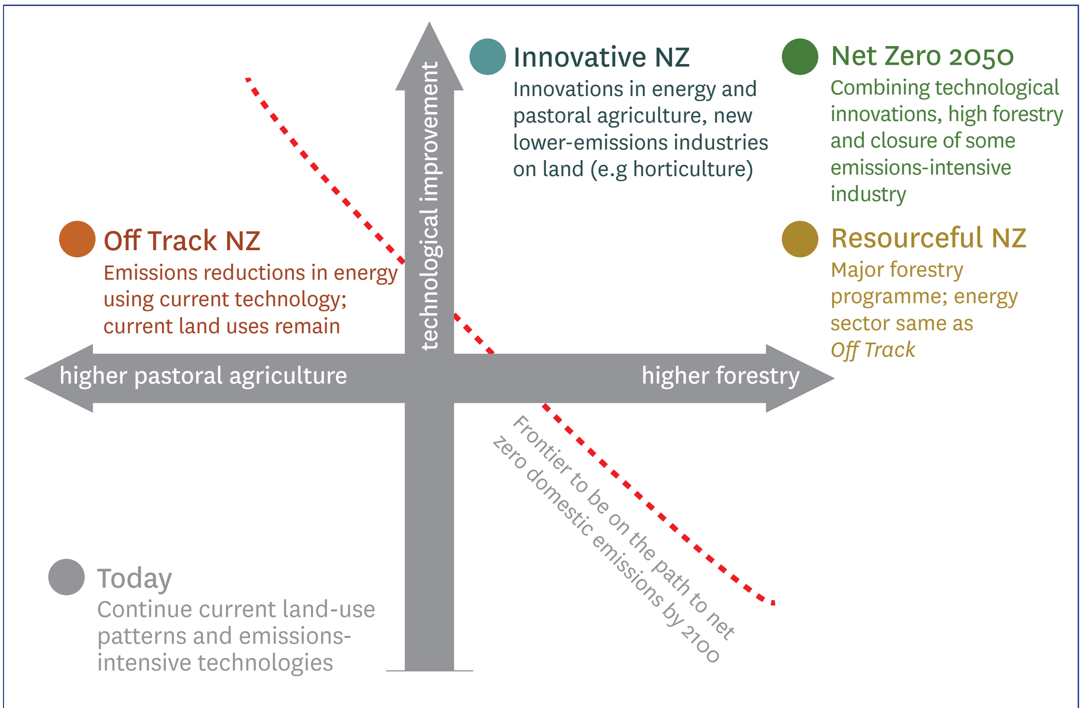
uncertain today whether technological improvement will occur to the level required to unlock an Innovative New Zealand, both Innovative and Resourceful New Zealand share a larger forestry sector, which could be pursued alongside a dynamic programme of energy sector decarbonisation that takes advantage of technological developments as they occur.

The absolute reduction in pastoral animal numbers in Resourceful New Zealand and Innovative New Zealand has different implications for global emissions depending on the extent of global action. As ensuring food security is a global imperative, reflected in both the Sustainable Development Goals and the Paris Agreement, these scenarios give rise to the concern that reducing agricultural production in New Zealand might simply increase it elsewhere, with no climate benefit (and possibly a worse outcome if production is shifted to a less emissions-constrained region). An alternative perspective recognises that achieving the Paris Agreement is likely to require substantial changes in the global patterns of food consumption and production. This could include reducing losses and waste in the supply chain; changing diets from animal products to plant-based food with equivalent protein content; and a reduction in over-consumption. Viewed from this perspective, the change in land-use patterns under these scenarios could be seen as an internally coherent strategy of building New Zealand's economic resilience in a low-emissions world.

Sustained deployment of permanent emission reductions is required beyond 2050 to continue the path to emissions neutrality; this will be particularly important in Resourceful New Zealand. Although the Innovative and Resourceful scenarios reduce emissions at a rate that is consistent with emissions neutrality in the second half of the century, the analysis does not include a full assessment of bottom-up emission reductions potential beyond 2050. Further reductions may be more challenging as many of the lower-cost opportunities will have been captured. The heavy reliance on net afforestation in Resourceful New Zealand poses particular challenges as the sequestration potential of forests diminishes as they reach maturity, and emissions are released after the timber is harvested. Scope for yet further afforestation is also limited in this scenario. Consequently, beyond 2050, New Zealand may well need to explore options that deliver negative emissions (in other words, that permanently remove emissions from the atmosphere). This might include, for instance, the use of bioenergy in combination with carbon capture and storage (CCS), but could also include the use of technologies that are not yet foreseen.

It is possible to reduce 2050 emissions by more than either the Innovative or Resourceful scenarios suggest. Figure 2 also depicts a Net Zero 2050 scenario in which New Zealand's net domestic GHG emissions are close to zero by 2050. This more ambitious scenario effectively combines both Innovative and Resourceful New Zealand. This rapid pursuit of the net zero goal in the domestic economy would be consistent with a focus on the aspect of the Paris Agreement that calls on countries to pursue *'efforts to limit the temperature increase to 1.5°C'*. The set of circumstances that would facilitate a Net Zero 2050 scenario are optimistic technological outcomes across agriculture and energy; substantial changes to land-use patterns; and industry closures across aluminium, refineries and iron and steel. This scenario has not been considered in detail in this report, first because of the even more marked changes it requires in New Zealand's emissions profile, but also because, analytically, it would largely involve combining two scenarios that have been considered in depth. However, there is likely to be interest in examining such a scenario in more depth in the future, especially as global research efforts at exploring the implications of a 1.5°C temperature target increase.

Figure 2. Scenarios differ by the level of technological progress and land-use patterns



Source: Vivid Economics

In pursuing the emission reductions envisaged in these scenarios, all members of New Zealand society will have a role to play, but they will need to be supported through new policy action. Some of the opportunities to reduce emissions will rely on the voluntary activity of firms and households, such as changing business models to capture value from low-emission innovation, transforming whole supply chains through new collaboration models, and creating innovation in financing tools to deliver low-emissions investment. However, while these opportunities abound, they will need a supportive policy environment in order to be unlocked. While it is not the purpose of this report to make detailed policy recommendations, a strong, predictable, emissions price should be a priority for policymakers to achieve any of the three scenarios. However, an emissions price alone will not address barriers and unlock abatement in all sectors. A comprehensive suite of policies should integrate price and non-price measures to overcome the multiple barriers to uptake of new technologies and approaches. Box 1 presents a summary of the conclusions and policy recommendations; a complete list, including more detailed aspects relevant to specific sectors, is included in Section 5.

Box 1 Summary of key conclusions and policy recommendations

Conclusions

1. Any pathway to reducing the country's domestic emissions will involve substantial change to patterns of energy supply and use, including moving towards a 100 per cent renewables grid and substantial electrification of the passenger vehicle fleet and low-grade heat.
2. It is possible for New Zealand to move onto a pathway consistent with domestic net zero emissions in the second half of the century, but only if it alters its land-use patterns.
3. If New Zealand does seek to move its domestic economy onto a net-zero-consistent trajectory, there is a choice between the extent to which it is able to make use of new technologies and the extent to which it needs to embark upon substantial afforestation. With some constraints, there will be an opportunity to flexibly adjust the rate of afforestation as the pace of new technological development and deployment becomes clearer.
4. If it chooses to substantially afforest and it is fortunate enough to benefit from the extensive availability of new technologies, it could be possible for the country to achieve domestic net zero emissions by 2050.
5. Although afforestation will likely be an important element of any strategy to move to a net zero emissions trajectory in the period to 2050, in the second half of the century alternative strategies will be needed.

Recommendations

1. The New Zealand government should develop a trajectory for emissions price policy values, to apply to all government assessments and analyses, that are consistent with what is required to deliver the objectives of the Paris Agreement. This would imply significantly higher values than seen in the New Zealand Emissions Trading System (ETS) today. This would help avoid the lock-in to a high-emissions infrastructure that makes attainment of a low-emissions economy impossible without the risk of asset stranding.
2. Encouraging the private sector to make investments consistent with a low-emissions future requires a robust and predictable emissions price. The extension of the emissions price to biological emissions from agricultural production would encourage land-use decisions to take account of the emissions intensity of different activities that use the land. It could therefore help facilitate the land-use change envisaged in the Resourceful and Innovative scenarios.
3. Emissions pricing needs to be accompanied by a range of changed market and regulatory arrangements, infrastructure deployment mechanisms, and specific support to address a range of additional barriers and market failures.
4. Globally, there is a case for further investment in the research and development (R&D) of low-emissions technologies. Given the attractiveness of the Innovative scenario, New Zealand might contribute further to this, particularly in areas where it offers comparatively strong expertise, advantages and needs. Options for collaborative research and experimentation across government, business and research institutions should be explored, while further international collaboration can facilitate rapid application of new approaches to local contexts.
5. Political parties should actively seek to identify and articulate areas of common agreement on climate policy in order to enhance policy coherence and predictability, while allowing room for an informed debate and party difference over policy design.
6. Independent institutions, backed by statute, can help assist both the Parliament and government in developing coherent national climate policy, and enhance informed citizen engagement. The analysis conducted by such an institution might include, for instance, identifying expected trajectories for emission prices, so as to help private-sector investors make informed decisions over long-lived investments, or identifying whether there are tensions between government plans to reduce emissions and other elements of its economic development strategy.

7. Policy-making should adopt a holistic approach, including both economic and cultural interests. All stakeholder groups should be taken account of in policy design, including a process of meaningful consultation with iwi and hapū, as per the Treaty of Waitangi's principle of partnership, to acknowledge their interests and aspirations.
8. There is an important need to upgrade the evidence base to support New Zealand's low-emissions pathway planning. The most acute need is for one or a series of energy- and land-system modelling tool(s) that generate bottom-up estimates of abatement opportunities and costs, and that take account of the interactions between sectors.
9. A particularly important area for further research and policy development is understanding and addressing the distributional implications of differing low-emissions scenarios, and the policy responses that might help alleviate any concerns.

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1 Introduction

The Paris Agreement marks a turning point in international climate diplomacy and signifies an intensification of efforts towards a low-emissions future. In November 2016, the Paris Agreement entered into force, having been ratified by nations representing over 55 per cent of total greenhouse gas (GHG) emissions. It sets a global aim to limit warming to below 2°C and to pursue efforts to limit it to 1.5°C. To achieve this aim, the Agreement sets a target for a *'balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century'*. In looking to meet these goals, developed countries are expected to continue to take the lead in reducing emissions, reflecting the principle of equity and common but differentiated responsibilities and respective capabilities (UNFCCC 2015).

Meeting the Paris Agreement requires steep reductions in all GHG emissions. GHGs consist of both short- and long-lived gases (see Box 2). Long-term global temperature increases are primarily a function of cumulative emissions of long-lived GHGs – especially carbon dioxide (CO_2), but also nitrous oxide (N_2O) and some fluorinated gases. Indeed, these gases will need to be reduced to net zero to reach any temperature goal; it is only the speed at which they reach net zero that will determine the global temperature increase. However, in the short-to-medium term, short-term GHGs such as methane (CH_4) also influence global temperature, sometimes potently, and very deep reductions of these gases will also be required to stabilise temperature increases.

To support the transition to these pathways, the Paris Agreement invites countries to develop, by 2020, 'mid-century, long-term low greenhouse gas emission development strategies'. At the time of writing, five countries had submitted their mid-century strategies: France, US, Mexico, Germany and Canada. At the 2016 UN Climate Change Conference in Marrakech (COP22), the UN Climate Champions for 2016 – France and Morocco – launched a new initiative, the '2050 Pathways Platform', aimed at supporting the development of such strategies through sharing of resources, knowledge and experience. New Zealand is one of 22 countries to support this initiative to date.

Scenario planning can play a crucial role in developing mid-century strategies and preparing for a net zero world. The role of scenario planning is not to make predictions of what the future will or should be. Rather, scenarios are *'plausible descriptions of how the future may develop based on a coherent and internally-consistent set of assumptions about key relationships and driving forces'*(Millenium Ecosystem Assessment 2005). The development of multiple scenarios allows the identification of robust strategies, trade-offs and potentially perverse outcomes. It supports decision making in complex systems.

Box 2. A primer on the science of climate change

Climate change is caused by an energy imbalance in the earth's atmosphere. Temperature increases result when the amount of energy entering the atmosphere exceeds the amount of energy leaving the atmosphere. *Radiative forcing* is a measure of the earth's energy imbalance at any point that can be attributed to GHG emissions.

Different GHGs have different radiative forcing at different points in time. Some GHGs have relatively high radiative forcing immediately after release to the atmosphere, which then declines over time. These 'short-lived' gases include CH_4 and various hydrofluorocarbons (HFCs). Other 'long-lived' gases have a relatively lower radiative forcing in the short term (and so contribute relatively less to short-term warming impacts), but their persistence in the atmosphere means they contribute substantially more to long-term warming. These include CO_2 and N_2O (Myhre et al. 2013).

In order to compare the warming impacts of different gases, international policymakers tend to compare their contribution to temperature change over a 100-year period (their so-called 100-year Global Warming Potential, GWP). This is intended to allow a comparison of the impact of different GHGs. On this basis, for instance, it is estimated that one tonne of CH_4 has 25–36 times the radiative forcing of one tonne of CO_2 over the 100 years from the point at which they are released to the atmosphere (Myhre et al. 2013; Forster et al. 2007). However, this 100-year threshold is, from a scientific perspective, arbitrary. In the short term (5–10 years), the temperature impact from one tonne of CH_4 will be much greater than 25–36 times that of one tonne of CO_2. This is important if the global community wants to avoid exceeding a particular temperature threshold, perhaps because of the concerns of irreversible damage this might cause. On the other hand, CO_2 will persist in the atmosphere for much longer than 100 years, contributing significantly more to additional warming than is factored into these GWP estimates. Nonetheless, 100-year GWP calculations are the basis of the internationally accepted approach to comparing GHGs, and are therefore the approach adopted in this report.[1]

In its net zero clause, the Paris Agreement does not distinguish between short-lived and long-lived gases; instead it states that the world will reach a '*balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases*'. Because their radiative forcing rapidly declines after they have been emitted to the atmosphere, the precise profile of emissions of short-lived gases that would be consistent with the *temperature* goals of the Paris Agreement remains an area of scientific inquiry. However, the Agreement text envisages all GHGs being included when aiming for a net zero world (UN 2015).

1 Specifically, this analysis uses a GWP for CH_4 of 25 and for N_2O a GWP of 298 based on Forster et al. (2007).

This report, commissioned by GLOBE-NZ[2], presents one of the first efforts in scenario planning to help New Zealand chart its possible low-emissions pathways across all sectors of its economy. It identifies a range of potential emissions profiles in 2050 consistent with alternative assumptions about how the New Zealand economy and land-use patterns might evolve; what these scenarios imply for emission reductions between 2014 and 2050; and the extent to which, therefore, the New Zealand economy is on track to meet emissions neutrality in the second half of the twenty-first century (mirroring the global goal articulated in the Paris Agreement). These emission profiles are analysed through the use of an 'emissions calculator', an Excel-based tool that calculates the impact of various emission reduction opportunities on emissions, demand for fuels, the size of certain industries, and land-use patterns.[3] The resulting scenarios are used to examine the opportunities, strategic decisions and trade-offs associated with a steep reduction in the country's domestic emissions by the second half of the century.

The scenarios are developed from the existing New Zealand evidence base, complemented by international experience where appropriate. Drawing from the existing evidence base has advantages and disadvantages. A key drawback is the challenge associated with trying to ensure that the multiple pieces of evidence are combined in a way that is consistent and coherent. However, a key advantage is that it helps reveal which parts of the evidence base are stronger than others, allowing priorities for a future research agenda to emerge.

The work has three specific objectives:

1. To build a shared understanding of the available data and evidence on abatement, costs and co-benefits associated with reducing emissions in New Zealand, as well as the priorities for new research.
2. To construct an indicative understanding of alternative 2050 scenarios for New Zealand's transformation towards a low-emission economy.
3. To identify strategic implications, key decisions and challenges faced by New Zealand, including barriers to the attainment of abatement in each sector of the New Zealand economy (recognising that much more detailed policy elaboration will be required in future).

There are a number of restrictions and limitations to the work. Most importantly, the work is predicated on New Zealand being part of a global effort to reduce emissions in line with the Paris Agreement goals. This is in keeping with deep decarbonisation studies conducted in other countries. In addition, the primary focus of the work is on the emission reduction opportunities that are available to New Zealand; while

2 This report is compiled under contract with GLOBE-NZ, a cross-party group of 35 members, drawn from all parties within the 51st NZ Parliament. The project, funded for GLOBE-NZ by a group of donors within New Zealand, covered the period 1 September 2016 to 28 February 2017.

3 Importantly, this is a very different methodological approach to the Computable General Equilibrium (CGE) modelling analysis that has been one of the main ways that the NZ government has assessed different emission reduction opportunities to date. On the one hand, the bottom-up calculator approach allows for consideration of a range of technological emission reduction opportunities that may not yet be in widespread use in the New Zealand economy, such as electric vehicles. It is also easier to take account of the likelihood of advancing global efforts to reduce emissions that tend to be excluded by assumption in CGE models. These benefits make this approach more appropriate for scenario development. On the other hand, CGE modelling approaches provide a more unified framework that allows for a more detailed understanding of the macroeconomic implications of a particular policy or scenario, taking into account interactions across an economy. Both approaches, and others, can play an important role in advancing the evidence base on New Zealand's decarbonisation efforts.

the work briefly discusses the possible role that purchases of international emission reductions could play, this is not the main area of focus. The analysis does not consider international aviation and maritime emissions. Neither does it consider the climate impacts, or New Zealand's appropriate adaptation response to those impacts that would be associated with a 1.5–2°C global temperature increase. Finally, as discussed in the conclusions, the evidence base is not yet sufficiently strong to allow a detailed understanding of the social and distributional implications of different scenarios.

The analysis included a substantial programme of engagement with stakeholders from government, business and civil society in New Zealand. The engagement was structured to provide sources of evidence and to challenge the outcomes of the analysis as they emerged. The report's authors are indebted to all of these stakeholders who gave their time and expertise so generously.

The outputs of the analysis are provided in two reports; this summary report provides the discussion of the key findings and policy implications. The technical report sets out the technical descriptions of each scenario, the assumptions, and sources.[4] In this first report, there are four further sections:

- the economic rationale for reducing emissions in New Zealand;
- a strategy for reducing emissions based on New Zealand's national circumstances;
- alternative 2050 scenarios;
- conclusions and recommendations.

4 Given the large amount of evidence synthesised for this work, the summary report cites only those sources not covered in the technical report.

2 The economics of emission reductions

At a global level, the benefits of reducing emissions to stabilise temperature increases are well established. The Stern Review was one of the first high-profile studies to conclude that the benefits of strong and early action on climate change outweigh the costs of not acting (Stern 2007). More recent studies have largely reinforced this conclusion, identifying that the economic costs of climate change might be even greater than originally considered when account is taken of the impact that climate change may have on productivity and hence long-run growth (Dietz & Stern 2015), and that the costs of taking climate action may be further justified as a means of providing insurance against the possibility that climate damages may be even worse than currently anticipated (Weitzman 2012).

A global reduction in emissions will help New Zealand avoid some of the climate impacts it would otherwise face. One of the key barriers to climate action is that its costs are borne locally, while the climate change benefits are felt globally. Nonetheless, New Zealand does stand to gain from global efforts to reduce emissions. The Intergovernmental Panel on Climate Change (IPCC) identifies that some of the key risks faced by New Zealand from climate change, but which could be mitigated by globally effective action, include potential flood damage from more extreme rainfall, and increased economic losses and risks to human life and ecosystem damage from wildfires. Although there is considerable uncertainty, rises in sea level could also significantly increase risks to coastal infrastructure and low-lying ecosystems (Reisinger et al. 2014).

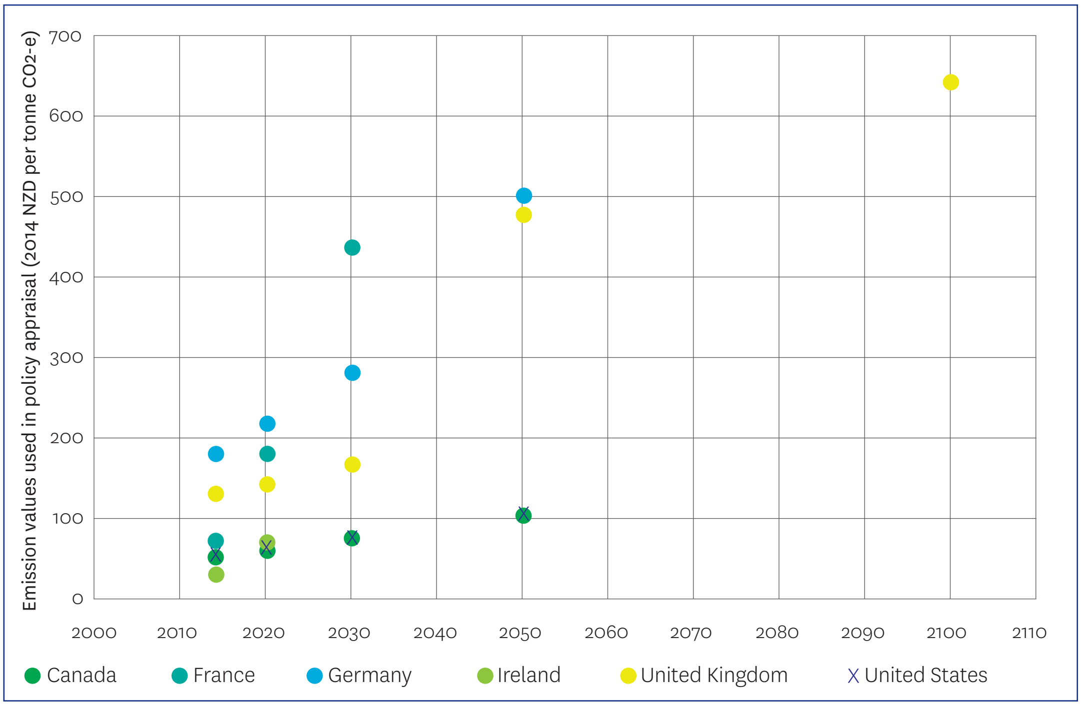
Steep emission reductions are required to meet the Paris Agreement objectives; to the extent that it is feasible to delay further, costs will only increase. These economic considerations are part of the reason why global leaders came together to craft and then ratify the Paris Agreement. To meet the 2°C target of the Agreement with 50–66 per cent probability at least cost, and taking into account the current commitments made by countries in the period to 2030, modelling suggests that carbon dioxide emissions will need to reach net zero by 2060–80s, and that total GHG emissions would have to reach net zero between 2080 and 2100 (Rogelj et al. 2016).[1] Unsurprisingly, economic analysis shows that delaying action, and hence reducing emissions over a shorter time frame to meet the same climate objective, necessitates much more costly and disruptive change, if indeed this is possible at all (den Elzen et al. 2010).

To help meet the temperature targets of the Paris Agreement, and/or to reflect the economic damage that emissions otherwise cause, numerous countries have developed emissions pricing policy values. These are the emissions prices that

1 Moreover, these analyses assume benign technological developments in the second half of the century that will allow so-called 'negative emission technologies' to turn the world's emission profile negative. If these technologies do not develop then even greater emission reductions will be required.

these countries consider as needing to be taken into account in policy and investment appraisal. They are derived in one of two ways. In some cases (including, on occasion, in New Zealand), they reflect an explicit attempt to quantify the damage that an additional tonne of emissions will cause, with the intention that investments or policies should proceed only when the benefits of an intervention exceed all of its costs, including the costs associated with additional emissions exacerbating climate impacts. On other occasions, they are set with the intention of ensuring that emissions fall on a trajectory that is consistent with either domestic policy targets or the temperature goals of the Paris Agreement. While there is often a high degree of uncertainty over how these values are derived using either approach, Figure 3 shows that they imply a profile for emissions prices that is much higher than those currently seen in the New Zealand ETS.

Figure 3. Emissions values used in policy appraisal in 2050 are above NZ$100 per tonne CO_2-e



Note: The exchange rate used for US$ to NZ$ is 1.38. Some countries only apply these emission pricing policy values to carbon dioxide emissions; other countries, including the UK and US currently apply them to all greenhouse gases covered by the Kyoto Protocol.
Source: Smith and Braathen (2015) and Vivid Economics

Relative to these policy values, there are plentiful opportunities for New Zealand to cost-effectively reduce its domestic emissions. Our analysis has sought to synthesise a wide range of evidence on the costs of reducing emissions in New Zealand. Compiling this evidence is challenging as small differences in calculation assumptions or approach can lead to different quantitative results. Rather than present precise point estimates of different abatement opportunities, it is more faithful to the evidence base to present them in broad low-, medium- or high-cost categories:

- *Low-cost* options are less than NZ$50/$tCO_2$-e in 2050, and may even be less than zero, if technologies become cheaper than their emissions-intensive alternatives. For example, if electric vehicles become cheaper than internal combustion vehicles, the abatement cost is below zero. Other low-cost options would likely include many forms of energy efficiency and afforestation.

- *Medium-cost* options are in the range of NZ$50–$100/tCO_2-e in 2050, and are likely to be cost-effective relative to the emission price policy values in 2050 identified above. They are likely to include electric heating options for industrial production and many uses of bioenergy, as well as the roll-out of electric vehicles to decarbonise freight.

- *High-cost* options are above NZ$100/$tCO_2$-e in 2050 and hence may be above typical emission price policy values in 2050. They could include the electrification of high-temperature heat for industrial production, electrification of rail, and decarbonisation of industrial process emissions and mitigation of fugitive emissions from, for example, geothermal or fossil fuel production.

Many sources of emission reductions also deliver important co-benefits. By reducing emissions, New Zealand might also:

- dramatically improve the quality of its water resources by reducing livestock production or nitrogen emission intensities,[2] one of the country's most salient public policy issues;

- stabilise river banks and improve soils, improve habitats and biodiversity, reduce water temperatures and algal growth in waterways, reduce rainfall-runoff events and improve visual amenity;

- improve health in cities through the transition away from internal combustion engines (ICEs), increased use of active transport, and improved insulation of building fabric leading to more comfortable and health-enhancing housing stock;

- enhance the country's energy security and susceptibility to fluctuations in international fossil fuel prices.

Indeed, from one perspective, it may be more valuable to consider many emission reduction opportunities as having desirable outcomes for public policy to seek, and that also happen to have the co-benefit of reducing emissions.

A shift towards a lower-emissions economy could also yield important dynamic benefits. In the same way that firms, industries and countries that are more productive in their use of labour, capital and raw materials are better able to compete in international markets, so, increasingly, it will be important to be able to make use of scarce rights to emit GHGs productively. New Zealand's low-carbon electricity generation means that it already has a clear opportunity to thrive in such a context. Furthermore, building on what is already an efficient and, by international standards, technologically advanced pastoral agricultural sector, there could be opportunities to develop comparative advantage in the technologies and production processes that can allow pastoral agriculture to cope with increasingly binding emissions constraints.

2 However this will depend partly on what use is made of the land. Some, but not all, forms of horticulture may be associated with similar rates of nitrogen leaching compared to pastoral agriculture.

Nonetheless, there will also be legitimate barriers and concerns associated with pursuing these emission reductions that will need to be actively managed. The transition to a low-emissions future will raise a number of wider socioeconomic concerns. Patterns of economic activity are likely to change, and with them the location of employment opportunities, and the skills needed to fulfil these opportunities. Energy prices will likely rise, at least in the short term, raising concerns around energy poverty and industrial competitiveness. New Zealand's flexible, adaptable economy and strong institutions already place it in a strong position to manage such a transition. However, additional, specific measures may be needed, such as compensation for those on low incomes or working in vulnerable industries, or skills training and vocational programmes to prepare for new areas of employment.

Given these concerns, the flexibility to be able to purchase emission reductions from overseas will remain important for New Zealand as it transitions towards a low-emissions future. New Zealand can contribute to the goals of the Paris Agreement either by reducing its emissions domestically or by purchasing emission reductions from overseas through the anticipated emergence of a revitalised international emissions market. Traditionally, New Zealand has seen the flexibility provided by this option as important given the perceived challenges and uncertainties it faces in reducing some of the sources of its domestic emissions, especially from the agriculture sector, as well as some of the broader socioeconomic challenges. The use of international emissions markets may also support low-emissions development in low- and middle-income countries. While the focus of this study is only on opportunities for domestic emission reductions, and has therefore not considered New Zealand's overall contribution to global mitigation or the optimal split between domestic reductions versus overseas purchases in that context, flexible access to these markets will clearly remain a crucial element of New Zealand's emission reduction strategy.

However, an over-reliance on international purchases also carries risks. New Zealand's recent experiences in purchasing international units from, for example, Ukraine, illustrate the reputational risks it might face in using international purchases, and how such purchases might threaten the genuine execution of New Zealand's contribution to global efforts to reduce climate risks. At the other end of the spectrum, there remains a significant degree of uncertainty regarding the future trajectory of international emissions prices. Ambitious implementation of the Paris Agreement by other countries could make them reluctant to sell emission reductions to New Zealand, preferring to keep them for use against their domestic targets, and forcing New Zealand into paying much higher prices than suggested in current forecasts.

In short, there is a strong economic rationale for New Zealand to consider carefully how it might substantially reduce its emissions, and what the consequence of this might be for its economy.

3 Strategic considerations in moving New Zealand to a low-emissions pathway

New Zealand's national circumstances create a particular set of challenges when moving to a low-emissions pathway. New Zealand's emission per capita and per unit GDP have fallen since 1990 but remain high by international standards. This is due to unusually high emissions from agriculture and high transport emissions intensities. Two characteristics in particular have an important bearing on when, how, and to what extent New Zealand might reduce its emissions:

- New Zealand benefits from abundant and diverse sources of low-carbon energy. Hydro, geothermal and, to a lesser extent, wind, solar and biomass resources are already being effectively deployed to deliver low-carbon electricity. Collectively, these account for around 80 per cent of electricity generation. By contrast, the OECD average is 24 per cent (IEA, 2015).

- As a proportion of gross emissions, New Zealand's biological emissions from agriculture are the highest among developed countries, at around 50 per cent of gross emissions. This is twice the OECD average (OECD 2015). Forestry, however, represents a significant carbon sink, sequestering about 30 per cent of gross emissions. Collectively, although agriculture and forestry account for a relatively small share of GDP – New Zealand, like other developed economies, is a predominantly service-sector economy – the products from these sectors account for around 70 per cent of the country's merchandise exports (Statistics New Zealand 2016; New Zealand Ministry for Primary Industries 2016).

Despite these distinctive characteristics, there are abundant opportunities for New Zealand to reduce its emissions, spanning all sectors of the economy and requiring action by all firms and households. The discussion below outlines some of the key strategic opportunities that exist, and highlights how, in many cases, these opportunities will deliver further benefits to the New Zealand economy and/or the quality of life of New Zealand's citizens. All firms and households will have a role to play in unlocking these opportunities, which will often require a change in business models, recalibration of supply chains, and innovations in financial vehicles. These changes will in many cases need to be guided and incentivised by government policy.

3.1 Energy sector emissions

The UN's Deep Decarbonisation Pathways Project[1] identified a common approach for reducing energy sector emissions – efficiency, decarbonisation (of electricity supply) and electrification (Deep

1 The Deep Decarbonisation Pathways Project is a global collaboration of energy research teams that seek to chart practical pathways to significantly reducing GHG emissions in their own countries.

Decarbonisation Pathways Project 2014). This also applies to New Zealand; however, because the country already has such a low-emissions electricity network, the approach is likely to be easier and more cost-effective than in many other countries. In turn, this provides the country with an opportunity to attract globally mobile energy-intensive industries in a world facing increasingly stringent emission constraints.

3.1.1. Efficiency

There are multiple opportunities for low-cost energy efficiency across all sectors in the New Zealand economy:

- *Buildings*: improvements in the insulation of existing homes and highly insulated new building stock.
- *Industry:* as a major user fossil based energy, industry offers one of the largest opportunities for energy efficiency.
- *Transport:* the fuel economy of New Zealand's transport fleet is poor compared with other developed countries, while moderating the expected growth in demand for car travel, especially in urban areas through increased cycling, walking and efficient urban design could lead to further gains.

Crucially, these opportunities are likely to be low-cost and to generate substantial co-benefits. International studies show that energy efficiency is often one of the lowest-cost ways to reduce emissions, sometimes bringing financial savings. This is corroborated by New Zealand evidence. It is also likely to deliver co-benefits for health from warmer homes, leading to fewer hospital visits and reduced sick leave. The internal combustion engine produces numerous tailpipe emissions which have detrimental, and sometimes severe, health impacts. More efficient transport modes would reduce these impacts.

A wealth of evidence demonstrates that a suite of policies are needed to unlock energy efficiency potential. While a strong and robust emissions price is an indispensable component of unlocking energy efficiency, it is not sufficient. A host of barriers (market failures) can block people and firms from undertaking beneficial energy efficiency investments. These include difficulties in accessing finance, landlord–tenant problems (where the benefits from energy efficiency flow to one person but the costs are borne by another), difficulties in accessing information, and systematic behavioural biases.[2] To tackle this suite of barriers, policymakers need a coherent suite of responses. In New Zealand, some of the biggest gaps in the policy suite appear to relate to new buildings, efficiency standards for the transport fleet, and improvements in the use of heat in industry.

2 This might include incorrect assessments of fuel savings or loss aversion.

3.1.2 Decarbonisation

There is scope for New Zealand to further decarbonise its electricity supply. Renewables already provide the lowest-cost source of electricity in New Zealand. There are plentiful renewable resources to accommodate the likely increase in electricity demand (see below), and the country's liberalised and flexible market provides appropriate pricing signals to develop this capacity as needed.

The key challenge for New Zealand is to be able to cope with seasonal dry periods which will threaten its hydro resources. The country's mix of renewable resources – especially geothermal and hydro – means that it does not face one of the most difficult decarbonisation problems faced by most other countries: how to keep the lights on when it is dark and the wind stops blowing. This provides the country with a significant advantage. However, a prolonged dry period can still create challenges as water levels in reservoirs fall. Gas generation can ensure security of supply in these (relatively rare) cases. To accommodate this, market arrangements may need to be revised to maintain system reliability, including incentives for new low-emissions generation as well as investment in a portfolio of measures to provide system flexibility, including demand-side response, flexible gas plant and batteries. The development of this new capacity, and the accompanying changes in regulatory rules, would allow New Zealand's remaining coal-fired generation to close.

3.1.3 Electrification

There is a significant opportunity for New Zealand to reduce its emissions through electrification of the passenger vehicle fleet.
The transport sector accounts for the largest proportion of the country's emissions from energy use. Improvements in the energy efficiency of existing vehicles, coupled with steady electrification of the vehicle fleet, would allow these emissions to be brought down substantially. Recent notable improvements in battery performance and cost suggest that this will be a lower-cost way of providing mobility than the internal combustion engine – potentially as soon as the 2020s. Moreover, it can help make New Zealand's cities cleaner and quieter and, along with the right arrangements and incentives, can play a role in helping to manage and stabilise the grid. Heavy goods vehicles are more difficult to decarbonise due to weight and distance constraints, although there is some scope for shifting freight from road to rail and electrifying rail use.

The biggest barrier to the development of the electric vehicle fleet is the high fixed cost of developing a charging infrastructure. As with other networks, the financing and operation of such infrastructure might require public intervention, especially to prime the market in the early years. This is an area for urgent policy focus.

Extending low-emissions electricity to the heat sector is a major mitigation option. The key technologies for deployment in low-grade heating applications include efficient heat pumps and resistive heating technologies. International studies suggest that there is likely to be scope to roll these technologies out to the majority of the building stock. While there is already an increasing use of heat pumps in New Zealand, further work is required to generate accurate estimates of the country's total potential. Where these technologies can be deployed, they are likely to be low and medium cost.

In medium-grade and industrial heating applications biomass from the forestry sector could be suitable, although cost varies depending on the specific application. Biomass could be used for applications with a high energy demand such as milk drying, although some upgrading of the biomass feedstock may be required in order to deliver heat to meet temperature and quality requirements. The management of transport costs and challenges in ensuring security of biomass supply have also been barriers to date.

3.2 Emissions from land

Addressing biological agricultural emissions is the most challenging issue for New Zealand's low-emissions pathway planning. Almost half of New Zealand's gross emissions are biological emissions from agriculture, the vast majority of which are from pastoral agriculture (New Zealand Ministry for the Environment 2016). While New Zealand's energy sector represents a valuable asset in a low-emissions future, its high proportion of biological agriculture emissions might, if not managed carefully, represent a substantial liability. On the other hand, New Zealand has an opportunity to identify its strategic response in a way that most other countries will only come to consider in a few decades from now. Many of the mitigation options identified, such as targeted breeding programmes, require sustained effort over decades to have full effect. By starting this process now, New Zealand may be able to gain an edge over its competitors..

There are a number of options for reducing emissions from agriculture while maintaining current land-use patterns Some of these options are available now, while others rely on technological developments that can be foreseen with more or less confidence:

1. *Reducing livestock numbers and land-use change:* By reducing livestock numbers, New Zealand could guarantee abatement for a given emissions intensity of livestock. This can be achieved through land-use change away from pastoral farming and/or through de-intensification.[3] Abatement quantities resulting from de-intensification are uncertain, although there is some evidence that de-intensified, low-emissions farms could maintain their profitability, or even improve it.

3 Reducing the number of animals per hectare of land.

2. *Improving farm- and animal-level efficiency.* Improved management practices on less-efficient farms could both increase productivity and reduce emissions intensity. An ambitious scenario for farm-level improvements would reduce their emissions intensity of production by about 10 per cent. Further improvements are possible with the adoption of precision farming techniques to optimise the use of farm inputs. In New Zealand-based case studies, the use of precision techniques has been shown to reduce fertiliser use while increasing pasture growth and productivity. Finally, selective breeding of low-emitting cattle and sheep could reduce agricultural emissions by a further 8–15 per cent. Generalisations of costs for these options are challenging given that they are likely to be farm-specific but, broadly, they are likely to be low given the potential for financial benefits to farmers from improved efficiency.

3. *Reducing emissions intensity of inputs*: This includes a range of options which change ruminant diet towards different grasses or fats. Introduction of new ryegrass varieties, currently being researched, have the potential to reduce CH_4 emissions by up to 15 per cent and N_2O by up to 17 per cent per unit of feed, though costs are uncertain. Other options to increase fat content could reduce emissions up to 4 per cent, although these options are likely to be high-cost in New Zealand given it requires a move towards feed lot system. Reducing dietary fibre content by substituting high-protein ryegrass for brassicas or maize silage are other options that have proved effective in trials internationally, although the evidence base for abatement potential and cost are weak in the New Zealand context.

4. *Improving management of animal waste and fertilisers:* The use of stand-off pads and animal housing techniques could lead to reductions in nitrous oxide emissions of up to 5 per cent per animal, with further abatement possible if methane from animal waste can be effectively captured and flared when animals are housed. However, these options are potentially high cost, with some evidence to suggest that they are feasible only where barns and stand-off pads are already in place. Application of nitrification inhibitors such as Dicyandiamide (DCD), which is primarily being developed to improve water quality, can reduce nitrous oxide emissions by up to 40 per cent on each hectare to which it is applied. DCD is currently undergoing testing to confirm its safety; its high cost means that its use is likely to be confined to the dairy industry.

5. *Emerging technologies:* Researchers are currently investigating options to reduce the amount of methane produced by livestock through the use of vaccines and inhibitors. While these options are not expected to be available until the 2020s, they may reduce emission intensities by more than any other option. Inhibitors have been shown to reduce methane emissions per animal by up to 30 per cent; however, they are not yet suitable for use in pasture-based agricultural systems like that of New Zealand. This problem could be overcome

by the development of a vaccine. Researchers are currently targeting a vaccine which could reduce methane emissions by at least 20 per cent. If successful, this is likely to be used widely in the livestock industry. While promising, these technologies face practical challenges in ensuring that they are suitable for pasture-based farm systems and that their use meets with consumer acceptance in export markets. If these challenges can be overcome, the costs associated with their use could be low or negative.

Barriers to agricultural mitigation can be significant, although a combination of pricing and regulatory policies can unlock many options. Agriculture is unusual in its production and emissions characteristics. Although there are global concerns about food security, emissions are often controlled by many diffuse agents that are often highly exposed to international competition. Moreover, mitigation options are often complex and highly context-specific, requiring in turn careful monitoring. The sector can also be subject to more generic mitigation barriers such as a lack of access to finance, institutional barriers and a lack of knowledge. Strategic policy can nonetheless unlock many abatement options. This will require price incentives for specific farm-based practices; continued support for R&D into emerging technologies; and support and regulatory action to address coordination problems.

However, a fundamental pivot point for New Zealand in deciding on low-emissions pathways is whether to significantly alter current land-use patterns. The extent to which these changes are made will have a fundamental bearing on New Zealand's long-term emissions. However, questions of land use do not influence just emissions; they will have a significant bearing on other public policy issues of national significance, not least water quality and the vitality of the rural economy. They also raise important issues around emissions leakage, discussed further in Box 3.

The most obvious alternative land use is forestry; as well as reducing the quantity of emissions-intensive activity, this option would also allow sequestration of carbon emissions. Afforestation could consist of both plantation forestry (where most of the carbon is sequestered temporarily) – and reversion to native forestry (which would sequester carbon permanently but, except where native plantations such as manuka are developed, would tend to generate less economic value). There is plentiful land available for afforestation. Moreover, afforestation offers the opportunity to reduce erosion, improve water quality, and generate a domestic bioenergy resource. However, there is considerable, and understandable, public concern about the social and environmental consequences of a significant afforestation programme, especially if focused on plantation forestry. These concerns relate to both the potentially difficult transition away from pastoral agriculture for rural economies, and a lost opportunity to reintroduce native habitat.

There are alternative rural land uses which would not lead to substantial sequestration but which may have fewer negative social and other environmental repercussions. Chief among these is horticulture: a highly profitable, high-growth industry which many New Zealand farmers are already pursuing as part of a risk-diversification strategy and to rotate soils. Horticulture export earnings have doubled in the 12 years to 2016 and the industry, including wine and flowers, is now worth NZ$5.5 billion (Horticulture New Zealand 2016). There could also be opportunities to increase the amount of land devoted to arable agriculture.

An emissions price signal would be an effective means to take account of the emissions intensity of the activity on the land. A significant determinant of land-use decisions is the underlying economic issue of which activities generate the most economic value. The extension of an emissions price to cover the biological emissions of the agriculture sector would help ensure that these decisions took account of the emissions costs of different land uses.

3.3 Sustained emission reductions beyond 2050

Finding further opportunities for emission reductions beyond 2050 may be more challenging. Many of the lower-cost opportunities to reduce emissions will have been captured. Furthermore, while forests reduce emissions while they are growing, this sequestration falls towards zero as forests reach maturity. As such, while the challenging nature of New Zealand's biological emissions profile means that forestry will need to play an important role in reducing emissions in the period to 2050, additional approaches will be necessary in order to reduce emissions in the second half of the century.

It is vital to begin laying the foundations for permanent emission reductions. The role of afforestation in reducing emissions in the first half of the twenty-first century is effectively a strategy that buys time to allow for new technologies to be developed and deployed in the second half of the century. It is difficult to predict what these technologies might be, although there is particular interest in those that deliver negative emission reductions, such as combining bioenergy with carbon capture and storage (BECCS) – which sequesters CO_2 from the atmosphere and then stores it underground – as well as direct air capture and carbon-storing materials (Committee on Climate Change (UK) 2016). Given the potential emissions liabilities New Zealand might store in its forest stocks in the next few decades, it will be important for the country to ensure that it places itself at the global frontier of understanding the scope and role of these technologies.

Box 3. Reducing emissions from the pastoral agriculture sector and other sectors with internationally traded products

In 2015, animal products accounted for 51 per cent of New Zealand's merchandise exports by revenue (Statistics New Zealand 2015). This was the country's most valuable category of exports, accounting for five times more value than the next most important export category (forest products). It indicates the sector's strong exposure to international competition.

This raises concerns about the competitiveness implications of efforts to reduce emissions from pastoral agriculture. If emission reductions impose additional costs on farmers, the competitive position of New Zealand's most successful export industry may be threatened, reducing domestic income and threatening employment.

However, agricultural practices can adjust to maintain agricultural profitability. First, alternative agricultural land uses might generate equivalent or greater value from the land: in the last 12 years, for instance, horticulture exports have grown faster than dairy exports. Studies also indicate that pursuing agricultural de-intensification – using fewer animals on the same quantity of land – can be an effective strategy to mitigate potential profit losses.

The same pressures also raise important questions regarding the global efficacy of policies that seek to reduce New Zealand's emissions by changing its land use. Given constant or growing global demand for animal products, any decrease in pastoral agriculture land use in New Zealand would likely be offset by greater production elsewhere. This would substantially reduce the global emission reductions resulting from New Zealand's actions. Indeed, it could potentially lead to an increase in global emissions, if the emissions intensity of production is higher elsewhere in the world.

However, in a world committed to the Paris Agreement, global patterns of food consumption and production could change dramatically. Most analysis of stabilising global temperature increases at 2°C or lower includes reducing losses and wastes in the supply chain; changing diets from animal products to plant-based food with equivalent protein content; and a reduction in over-consumption. Significant technological advances could also lead to the rapid development of low-cost synthetic milk and meat substitutes. Viewed from this perspective, the change in land-use patterns under some of these scenarios could be seen as an internally coherent strategy for building New Zealand's economic resilience in a low-emissions world. It also need not compromise New Zealand's long-run economic performance.

Emissions leakage concerns apply to other emissions-intensive sectors where products are traded internationally. In New Zealand, some of the most salient industrial sectors where this may be a concern include refineries, steel manufacturing and food processing. Again, in a world that is collectively committed to achieving the Paris Agreement goals, these concerns would be expected to diminish over time. In the short-to-medium term, when countries may make progress towards implementation of the Paris Agreement at different speeds, there is a growing body of evidence on how to design emission mitigation policies in a way that can help alleviate such concerns (Partnership for Market Readiness 2015).

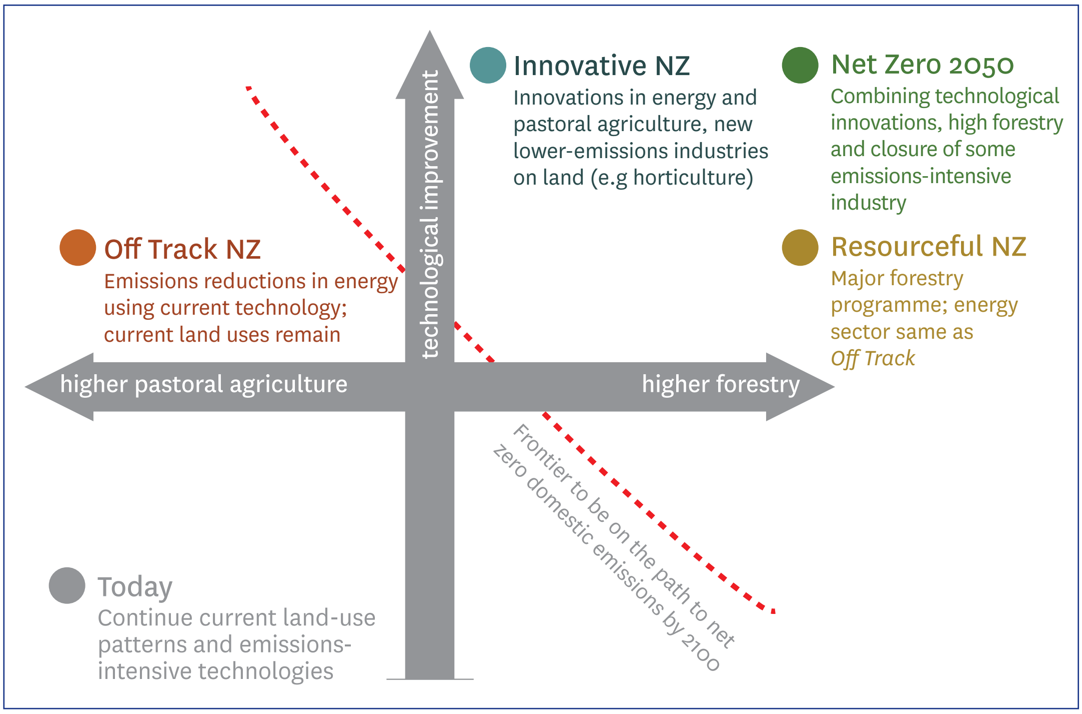
4 Alternative scenarios for New Zealand's domestic decarbonisation

This section presents alternative scenarios for domestic decarbonisation in New Zealand in the period to 2050, building on the strategic considerations presented above. All of these scenarios involve a significant departure from the technologies and practices commonplace in New Zealand today, although, within this context, they span a range of levels of ambition. At one end, the reductions are insufficient to place the country on a trajectory towards emissions neutrality in the second half of the century, and imply smaller percentage reductions than other countries have committed to. At the other end, the analysis shows how it might be possible for New Zealand to reach net zero emissions domestically by 2050, implying a more extensive percentage reduction in emissions than virtually any other country has committed to.

The different scenarios vary across two key dimensions: the extent of deployment of low-emissions technologies and patterns of land use. Relative to today (shown in the bottom left-hand corner of Figure 4), all scenarios envisage a far greater deployment of low-emissions technologies. However, in Off Track New Zealand, there is no significant change in the pattern of land use. The chart shows that this results in the country not being on a trajectory to achieving net zero emissions domestically by 2100. Innovative and Resourceful New Zealand, by contrast, both involve changes to patterns of land use. In Innovative New Zealand, there is a shift towards a more diversified pattern of land use coupled with greater development of new technologies, whereas in Resourceful New Zealand technology penetration is no more advanced than in Off Track New Zealand, but land use shifts decisively towards forestry. Both scenarios are consistent with the economy moving to domestic net zero emissions by 2100. As such, they are likely to be consistent with New Zealand's domestic emissions following the same profile of reduction as will be required globally in order to restrict temperature increases to less than 2°C.

Figure 4 also depicts an alternative scenario that has not been developed in detail. Net Zero 2050 presents a combination of the substantial technology development of Innovative New Zealand coupled with the decisive shift towards forestry in Resourceful New Zealand. This would allow the economy to move quickly towards net zero emissions, potentially by as soon as 2050. This is a profile of domestic emission reductions that is likely to be consistent with global reductions needed in order to realise the aspiration of the Paris Agreement to restrict temperature increases to 1.5°C. On the other hand, the chart also shows that with current patterns of land use, no

Figure 4. Scenarios differ by the level of technological progress and land-use patterns



Source: Vivid Economics

amount of (foreseeable) technology development will put the country on a trajectory towards net zero emissions.

Table 2 and Table 3 provide a detailed quantitative depiction of the different scenarios across a wide range of variables, relative to 2014 levels.

4.1 Common characteristics of the scenarios

All three scenarios involve significant decarbonisation of the energy sector. Specifically, they involve significant take-up of energy efficiency opportunities, along with almost complete decarbonisation of power, transport and low-grade heat. Many of these opportunities are available at low cost and/or have significant co-benefits. As such, in a world in which all countries are moving towards the Paris Agreement goals, they are consistent with the continued growth of the New Zealand economy and improvement in the quality of life of its citizens.

The amount of electricity generation increases from 42 TWh to 76 TWh in Off Track and Resourceful New Zealand, and reaches 90 TWh in Innovative New Zealand. This implies substantial investment in new renewable capacity leading to a system that is almost entirely based on renewables. It has not been possible to model the precise investment in capacity required to support this level of generation; however, new investment would be needed across wind, hydro and geothermal resources. The cost of providing this new generation is likely to be lower than that of fossil fuel generation. Additional sources of flexibility are required to support this system. Much of this can be provided by demand-side response, which is a low-cost option that is easily facilitated by New Zealand's flexible power market. Further investment in storage and gas may also be required, as well as in new grids, which would increase costs. New Zealand's coal-fired power generation is phased out. These options largely rely on mature, proven technologies.

In the transport sector, the passenger vehicle fleet is largely decarbonised by 2050 with 3.5 million electric cars and light commercial vehicles on the roads. Electrification reaches at least 85 per cent in 2050; this is realistic, even factoring in the unusually long lifetime of the New Zealand fleet and slow turnover of the stock. International projections suggest that cost parity with the Internal combustion engine could be achieved by the late 2020s. Prior to this,

Table 2. Assumptions and outcomes – macro, energy, industry and waste

	2014	Off Track 2050	Innovative 2050	Resourceful 2050
Central assumptions				
GDP (NZ$ billion 2009-10 constant)	211.3	422.4	422.4	422.4
Population (million)	4.5	6.1	6.1	6.1
Energy and transport				
Emissions intensity (kg CO_2-e/GDP)	0.27	0.12	0.04	0.05
Energy intensity (MJ/$GDP)	2.86	1.33	1.25	1.36
Energy delivered (GWh)	164,892	150,259	140,288	153,592
Electricity (total)	39,206	70,926	83,414	71,347
Heat and direct energy	107,866	120,103	116,103	123,436
Electricity	39,148	61,668	72,784	62,089
Direct fuels	68,718	58,434	43,318	61,347
Transport	57,026	30,156	24,185	30,156
Electricity	58	9,258	10,630	9,258
Direct fuels	56,968	20,898	13,555	20,898
Electricity generation (GWh)	42,193	76,330	89,769	76,782
Coal	1,831	736	0	741
Gas	6,567	6,132	1,795	6,168
Hydro	24,076	29,076	29,076	29,076
Geothermal	6,871	17,089	17,954	17,190
Solar	17	1,996	3,591	2,007
Wind	2,192	20,226	36,456	20,518
Biofuels	585	1,007	898	1,013
Other	54	68	0	69
Renewable (% of total)	80%	91%	98%	91%
Industrial processes				
HFC refrigerants (Mt CO_2-e)	1.5	0.2	0.2	0.2
Waste				
Waste per capita (kg)	735	620	504	620
Additional waste recycled	n/a	8%	9%	8%
Emissions per tonne waste change from CH_4 capture	n/a	-12%	-18%	-12%

Source: Vivid Economics

Table 3. Assumptions and outcomes – agriculture and forestry

		2014	Off-Track 2050	Innovative 2050	Resourceful 2050
Agriculture Livestock numbers (million)					
	Dairy	6.7	6.7	5.4	6.0
	Beef	3.7	3.7	2.6	3.0
	Sheep	29.8	29.8	19.7	22.5
Productivity (index 2014 = 100)					
	Dairy (milk, litres)	100	115	125	115
	Beef (kg weight)	100	115	115	115
	Sheep (kg weight)	100	115	115	115
Impact on emissions intensity of production from mitigation options (in 2050 for specified GHG)					
Vaccine + inhibitor (CH_4)					
	Dairy	n/a	-16%	-30%	-16%
	Beef	n/a	0%	-18%	0%
	Sheep	n/a	0%	-18%	0%
Selective breeding (CH_4)					
	Dairy	n/a	-15%	-15%	-15%
	Beef	n/a	-15%	-15%	-15%
	Sheep	n/a	-15%	-15%	-15%
DCD (N_2O)					
	Dairy	n/a	-8%	-8%	-8%
Accelerated performance and precision agriculture (N_2O and CO_2)					
	Dairy	n/a	-10%	-10%	-10%
	Beef	n/a	-3%	-3%	-3%
	Sheep	n/a	-3%	-3%	-3%
low-emissions feeds (CH_4 and N_2O)					
	Dairy	n/a	-7%	-7%	-7%
	Beef	n/a	-1%	-1%	-1%
Forestry Average new planting rates 2015-70 (ha per year)					
	Exotic species	n/a	9,300	27,709	37,936
	Natives	NA	0	9,091	18,182
Long run average carbon stock (tCO_2/ha)					
	Plantations	n/a	372	364	355
	Natives (at 50 years)	n/a	324	324	324
Sequestration rates on newly forested land (Mt CO_2-e per year) averaging approach excluding harvested wood products 2040-59 average					
	Natives	n/a	4.7	14.1	18.9
	Plantation forests	n/a	0.0	3.0	6.0
2100 in year					
	Plantation forests	n/a	0.0	0.0	0.0
	Natives	n/a	0.0	0.3	0.6
Land use (million hectares)					
	Farmland	12.4	11.5	10.6	9.8
	Plantation forestry	1.7	2.1	2.9	3.3

Source: Vivid Economics

a programme to develop charging infrastructure in urban areas where demand is likely to grow initially is likely to require a degree of government support. Electrification spreads to the heavy vehicle sector but at a slower pace, reflecting the greater technological challenges associated with electrifying this part of the fleet, with 25 per cent of heavy vehicles electrified by 2050.

Low-grade heat is substantially electrified by 2050; at least 75 per cent of these energy requirements are provided by electricity. This requires 22 TWh of electricity in 2050, more than doubling the amount of electricity used for low-grade heat in 2014. This growth is concentrated in the residential, retail and services sectors. This switch to electrification can be undertaken as existing building stock and appliances reach the end of their useful life, and it makes use of technologies that are already established.

Industrial process emissions remain flat or decline. Emissions from potent refrigerant gases fall significantly, dropping by 85 per cent from 2014 levels in line with New Zealand's commitments under the Kigali amendment to the Montreal Protocol. At the same time, uncertainties regarding New Zealand's heavy industry composition have a major influence, with petroleum, aluminium and iron and steel industries facing an uncertain future. Emissions from the production of building materials increase as construction grows to keep up with population growth.

Agriculture sees continued increases in productivity and reductions in emissions intensities. Farm- and animal-based efficiency improvements are accelerated, while process improvements like precision agriculture further reduce emissions intensity by reducing fertiliser use. Targeted breeding of livestock leads to lower-emissions breeds, cutting the production of methane per animal by 15 per cent. The expansion of new feeding regimes that are higher in fat and lower in fibre reduce methane emissions by up to a further 10 per cent on the farms on which they are introduced. Nitrification inhibitors are reintroduced to treat waste on some dairy farms, improving water quality, while the spread of methane inhibitors in the dairy sector cuts methane further still. Overall emissions per dairy cow decrease by about 23 per cent, and 10 per cent for beef cattle and sheep. Emissions decline by a greater amount per tonne of product, by 33 and 22 per cent respectively. This would require ongoing support for R&D into new technologies, particularly the development and commercialisation of methane inhibitors and vaccines, alongside the expansion of price incentives to the agricultural industry.

Plantation forestry continues to expand over the next 50 years, adding at least 0.5 million hectares to the forest estate. Deforestation halts, and the use of forest biomass is transitioned to longer-lived products and bioenergy. Production of paper remains stable, while the use of forest biomass for construction materials, furniture and other solid wood products increases by at least 75 per cent. Use of biofuels expands for process heat, providing all the intermediate process heat required by the pulp, paper, wood- and dairy-processing industries.

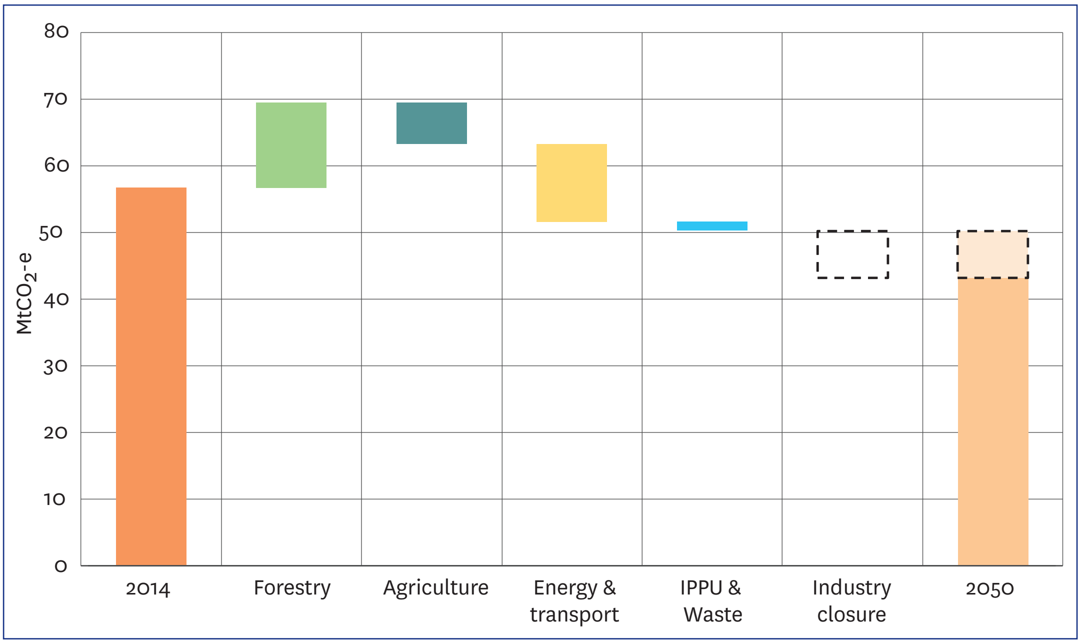
New Zealanders reduce the amount of waste they produce per person, and a greater proportion of methane emissions from waste are captured and combusted. Quantities of organic household waste are reduced through a combination of recycling and composting. A larger share of the waste from construction and demolition is sorted at source and thus diverted away from landfill sites. Unmanaged disposal sites, including farms, are regulated to enable better measurement and management of emissions. These changes largely make use of existing technologies such an anaerobic digestors and methane-capture technologies.

4.2 Off Track New Zealand

In Off Track New Zealand, there are no further efforts at reducing emissions, beyond those common to all scenarios. In particular, dairy, beef and sheep numbers remain the same as they are today. Given modest increases in stocking rates, this leads to the amount of land devoted to pastoral agriculture decreasing by about 10 per cent to 2050. Afforestation and changed uses of forest biomass mean that the forest sector remains a net carbon sink; net sequestration averages 11.5 MtCO_2-e during 2040–59, compared with 24.4 Mt of sequestration in 2014. Despite the emission reductions from agriculture and energy and transport – 9 MtCO_2-e and 12 MtCO_2-e respectively – reduced forestry sequestration means that net emissions remain persistently high.

Net emissions in Off Track New Zealand are around 43–50 MtCO_2-e in 2050, a 10–25 per cent reduction on today's levels (see Figure 5).

Figure 5. In an Off Track New Zealand, emissions fall by 10–25 per cent by 2050 compared with current levels



Note: The figure shows net emissions/removals from each sector relative to 2014. For instance, reduced sequestration from forests results in an increase in emissions in 2050 compared with 2014. Uncertainty in industrial structure reflects potential closure of some energy-intensive industries (especially aluminium smelting, iron and steel production and petroleum refining). Emission reductions are reported on a net-to-net basis, compared with 2014 – the most recent data for emissions – as this represents, in the authors' view, the most transparent and easy-to-understand metric for assessing the extent of change from 2014 emissions and progress towards a net zero goal. Gross-to-net and gross-to-gross comparisons can be made using the figures reported in Table 1. IPPU, Industrial processes and product use.

Source: Vivid Economics, 2014 emissions from New Zealand Ministry for the Environment (2016)

The appeal of this scenario is that it focuses only on emission reduction opportunities that are low or medium cost (using the definitions in this report) and/or that deliver significant co-benefits to New Zealand. All of the decarbonisation opportunities pursued in this scenario are expected to have abatement costs of around or less than NZ$100/t$CO_2$e, the threshold identified in Section 2. Indeed, the cost of many of these opportunities is already, or is expected to turn, negative over the period to 2050, including much of the energy efficiency potential as well as the electrification of the vehicle fleet. Many of these opportunities also come with significant co-benefits, especially improving health through a better, more insulated building stock and reduced tailpipe emissions.

Off Track is more ambitious than a business-as-usual trajectory. Even though this scenario focuses on low-cost abatement and/or where co-benefits are plentiful, it will still require change in behaviours and economic activity, stimulated by strengthened policy. By 2050, New Zealand would have an entirely different light duty passenger vehicle fleet, more energy provided through electricity, more energy-efficient buildings, and a substantial reduction in emissions per animal. This will require concerted policy effort.

However *because it does not involve a significant change in land-use patterns*, this scenario does not place the New Zealand economy on a trajectory to net zero emissions domestically by 2100. Even allowing for further emission reductions beyond 2050, the country will remain well above net zero domestic emissions in the period to 2100.

4.3 Innovative New Zealand

Innovative New Zealand couples the exploitation of more radical and uncertain technology developments – in both the energy and agriculture sectors – with a move to a more diversified pattern of land use. In contrast to Off Track New Zealand, these changes are sufficient to place the economy on a trajectory to domestic net zero emissions in the second half of the century. It provides a profile of domestic emission reductions that, if matched globally, would likely be sufficient to restrict temperature increases to not more than 2°C above pre-industrial levels, as specified in the Paris Agreement.

The major changes to the energy sector involve a suite of technological advances and/or lower-than-expected deployment barriers:

- Extending electricity to around one-third of high-grade heat demand, reflecting the availability of new electric technologies to provide high-temperature heat (for example, using resistive or inductance heating techniques). The level of electrification of residual medium-grade heat (after the use of bioenergy is accounted for) is also doubled and almost all low-grade heat is electrified.
- In freight, advances in the rail network enable a greater shift from road to rail (up to around one-quarter of freight shifts to rail).
- Faster-than-expected cost reductions for batteries and high uptake of demand-side response allow a greater percentage of wind and solar to be accommodated on the grid (renewables penetration increases from 95 to 98 per cent).

In the agricultural sector, the introduction of vaccines, which are currently being researched, reduces methane emissions and reshapes the emissions profile of pastoral agriculture. New Zealand-based researchers are aiming to produce a vaccine that would reduce emissions from enteric fermentation by at least 20 per cent without any productivity penalty. Enteric fermentation is the source of nearly three-quarters of New Zealand's agricultural emissions, as such, the development of a vaccine could have a major impact on New Zealand's emissions profile.

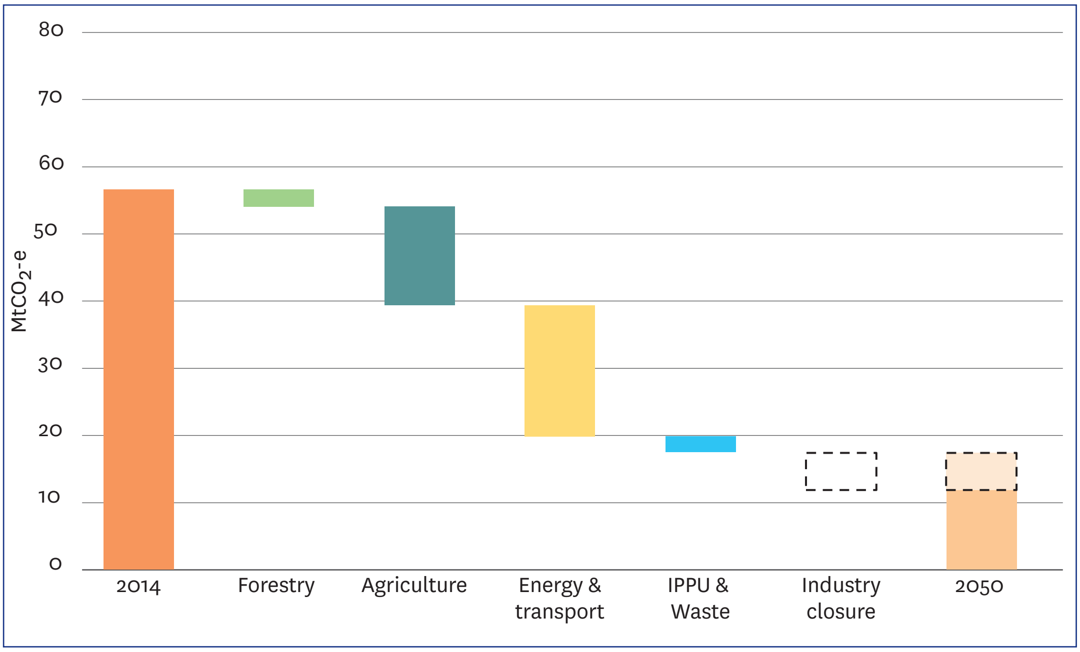
Critically, there is also a reduction in livestock numbers which is accompanied by land-use change. In this scenario, de-intensification of dairy results in lower numbers of more-productive dairy cattle, using an unchanged proportion of land. Reducing stocking rates can be associated with lower emissions intensity and maintained profitability when combined with higher feed-conversion efficiency. At the same time, a reduction in the number of beef cattle and sheep, alongside increased stocking rates, frees up 3.2 million hectares for other uses. Of this, 1.5 million hectares transitions to horticulture production and other crops, and a further 1.5 million hectares is used for new plantations or reverts to indigenous forest by 2050. The combination of changed land-use practices and lower-emissions intensities reduces emissions from livestock relative to the Off Track New Zealand scenario by 10.3 MtCO_2-e in 2050. This is somewhat offset by higher emissions from the production of horticulture and crops, which increase emissions by 1.8 MtCO_2-e.

The afforestation in this scenario creates a renewed carbon sink. Sequestration from forests and increased carbon stocks in wood products result in sequestration that is 15.3 MtCO_2-e higher than in the Off Track scenario, and 2.4 MtCO_2-e higher than today.

Accelerated reductions in levels of waste produced, and enhanced methane capture and combustion reduce emissions from waste by a further 1.1 MtCO_2-e, while industrial process emissions remain largely unchanged from the off-track scenario.

This scenario substantially reduces New Zealand's emissions in 2050 to 12–17 MtCO_2-e, a 70-80 per cent reduction compared with today's levels. This is significantly lower than what is delivered in Off Track New Zealand, and is enough to place the economy on a path to net zero emissions by 2100, with long-lived greenhouse gas emissions already below zero by 2050. Compared with today, a larger forestry programme reduces emissions by an additional 2.4 MtCO_2-e, with a further 22.4 MtCO_2-e of reduction coming from the energy and transport sectors, and 14.9 MtCO_2-e of reduction in the agriculture sector.

Figure 6. In an Innovative New Zealand, emissions fall by 70–80 per cent by 2050 compared with current levels



Note: The figure shows net emissions/removals from each sector relative to 2014. Uncertainty in industrial structure reflects potential closure of some energy-intensive industries (especially aluminium smelting, iron and steel production and petroleum refining). Emission reductions are reported on a net-to-net basis, compared with 2014 – the most recent data for emissions – as this represents, in the authors' view, the most transparent and easy-to-understand metric for assessing the extent of change from 2014 emissions and progress towards a net zero goal. Gross-to-net and gross-to-gross comparisons can be made using the figures reported in Table 1.

Source: Vivid Economics, 2014 emissions from New Zealand Ministry for the Environment (2016)

This scenario delivers a domestic economy that is on a trajectory towards net zero emissions in the second half of the century in a way that provides for a plurality of land uses. The land-use patterns could underpin a vibrant and prosperous rural economy that also contributes to reduced land degradation. These benefits are in addition to the health and quality-of-life benefits delivered by the energy sector decarbonisation that is also an integral element of this scenario.

However, it is heavily reliant on a series of technological advances whose feasibility and costs remain uncertain and which, if they fail to materialise, would make this scenario high cost or unattainable. Some recent developments give cause for optimism over the cost of low-emissions technologies. For example, solar PV and battery costs have fallen much more quickly than almost all analysts anticipated just a few years ago. In New Zealand, agriculture emission intensities have fallen significantly, in part due to new technologies and farm practices. At the same time, globally, low-emissions R&D programmes are generally considered to be substantially underfunded, and technologies like advanced biofuels and CCS continue to develop less quickly than initially hoped. To coherently plan on the basis of this scenario, New Zealand would need to be confident that a wide range of low-emission technologies will come to fruition. It would make sense to match this with an increased contribution to the significant scale-up of research spending that is needed for these technologies, in a manner consistent with the country's emission profile and comparative advantage.

4.4 Resourceful New Zealand

Resourceful New Zealand allows the economy to be consistent with domestic net zero emissions (and a domestic profile of emission reductions consistent with the global goal of restricting temperature increases to 2°C) without needing to rely on uncertain technological developments; it does so by making much greater use of the country's land resource to sequester carbon. In comparison with the balance of land patterns in Innovative New Zealand, a significantly greater proportion of land is allocated to afforestation.

Livestock numbers are lower than in the Off Track scenario but higher than the Innovative scenario. International demand for agricultural products declines, alongside changed consumer preferences and further development of plant-based or synthetic substitutes; however, this occurs at a slower rate than in the Innovative scenario. Across the board, increases in stocking rates enables 2.9 million hectares of pastoral land to transition to other uses.

This is a 'maximum' afforestation scenario with an additional 2.3 million hectares of forestry to 2050. Much of the excess pastoral land converts to plantation forestry, and 1.6 million hectares are planted by 2050, as the rate of new plantings grows to 55,000 hectares per year. Much of the remaining land is allowed to revert to native forests, with 0.7 million hectares reverting by

2050, providing additional sequestration and connecting native habitats. At the same time, a doubling in the production of horticulture and crops, utilises an addition 0.5 million hectares.

At the same time, the uses of forest products transition away from short-lived products to long-lived, higher-value products. Exports of pulp and woodchips declines, while paper production remains at current levels. Production of long-lived products like sawn timber, construction material and furniture more than doubles, reflecting both their higher rates of carbon sequestration and their potential higher value in domestic and export markets. At the same time, the use of biomass as fuel expands, providing all the medium-grade heat (100–300°C) required by the paper-, pulp- and wood-processing industries, and three quarters of the medium-grade heat required for low-emissions processing of agricultural products.

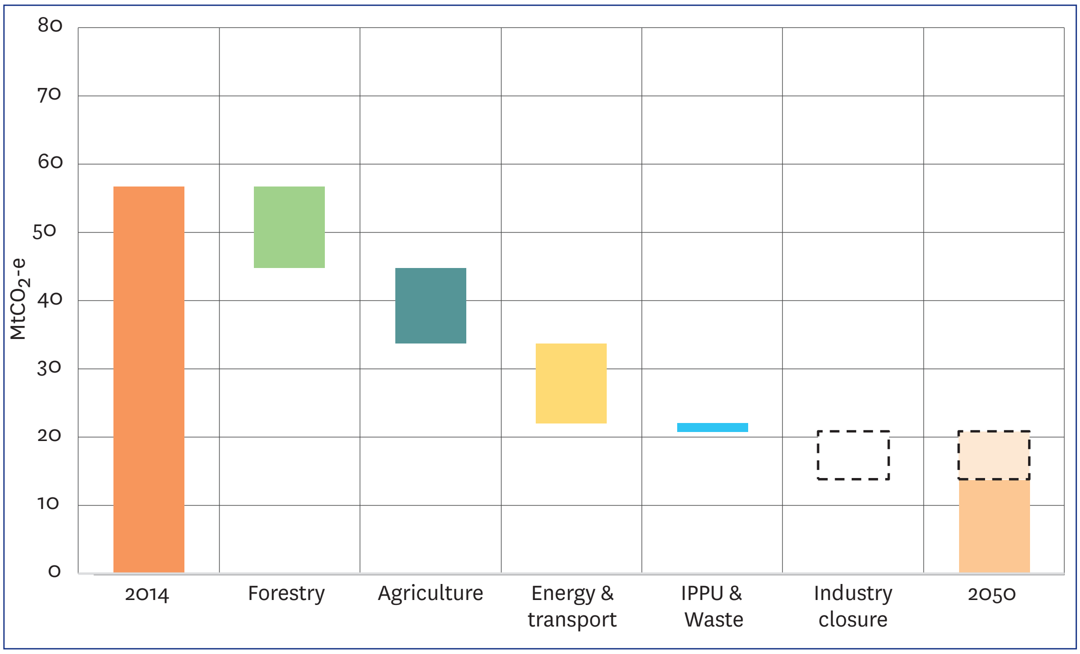
This increase in forestry, alongside changes to the end-use of wood products, means that the forest sector sequesters an average of 36.4 $MtCO_2$-e per year between 2040 and 2059.

These rates of planting are feasible at low-to-medium emissions prices. New Zealand has a mature forest sector which is highly responsive to emission price incentives. Ensuring that these incentives remain credible and enduring will be crucial to maintaining planting at the relatively high levels assumed in this scenario.

Aside from these differences, the scenario is very similar to Off Track New Zealand. New Zealand achieves significant energy efficiency improvements, bases its grid almost entirely on renewables, and electrifies its transport fleet and low-grade heat. In addition, relative to 2014, waste production falls – a greater proportion is diverted from landfill and a high proportion of methane emissions at waste sites are captured and combusted.

This scenario substantially reduces New Zealand's emissions in 2050 to 14-21 $MtCO_2$-e, a 65-75 per cent reduction on today's levels. This is an emissions level significantly lower than delivered in Off Track New Zealand, and is enough to place the economy on a path to net zero emissions before 2100. Indeed, as with Innovative New Zealand, long-lived greenhouse gas emissions are already below zero in 2050 in this scenario. While Resourceful New Zealand's larger forestry programme delivers significant abatement, its slower technological progress compared with Innovative New Zealand results in less abatement in the agriculture and energy sectors.

Figure 7. In a Resourceful New Zealand, emissions fall by 65–75 per cent by 2050 compared with current levels



Note: The figure shows net emissions/removals from each sector relative to 2014. Uncertainty in industrial structure reflects potential closure of some energy-intensive industries (especially aluminium smelting, iron and steel production and petroleum refining). Emission reductions are reported on a net-to-net basis, compared with 2014 – the most recent data for emissions – as this represents, in the authors' view, the most transparent and easy-to-understand metric for assessing the extent of change from 2014 emissions and progress towards a net zero goal. Gross-to-net and gross-to-gross comparisons can be made using the figures reported in Table 1.

Source: Vivid Economics, 2014 emissions from New Zealand Ministry for the Environment (2016)

This scenario is attractive in providing a cost-efficient and relatively certain way for New Zealand to move onto a trajectory consistent with a domestic net zero constraint. At an aggregate level, it is consistent with the continued growth of the New Zealand economy and it means that the country is not exposed to the risks of uncertain technology developments. The change in land-use patterns would also contribute to improving New Zealand's water quality and reducing land degradation.

However, the substantial change in land-use patterns implies significant social and environmental challenges. Socially, it would imply profound changes to rural livelihoods and New Zealand's rural economy. While many countries will face similar challenges with the move to a low-emissions pathway (for example, countries heavily reliant on coal production), changed land uses may require a difficult transition for rural economies. Furthermore, the expansion of plantation forests represents a lost opportunity to reintroduce native habitat. The heavy reliance on afforestation in the period to 2050 will also increase the urgency of finding alternative emission reduction options and technologies in the period beyond 2050.

4.5 Net Zero in 2050

Net Zero in 2050 might combine the forestry growth in Resourceful New Zealand (along with its agricultural productivity and stocking rate assumptions) with the technology penetration and livestock numbers of Innovative New Zealand. Although this scenario has not been considered in detail in this report, indicative calculations suggest that, in combination with industrial closure in the aluminium, steel and refinery sectors, it would be sufficient to drive New Zealand to close to net zero total GHGs by 2050: reaching about 2 Mt CO_2-e. In comparison with the other scenarios, this would be more consistent with New Zealand's domestic emissions profile following the global profile that is likely to be needed to meet the lower-end (1.5°C) aspirational temperature goal defined in the Paris Agreement.

There may be interest in exploring this scenario in future work.
This analysis has not considered the Net Zero in 2050 scenario in detail, largely because it is likely to require all of the elements considered in both Resourceful and Innovative New Zealand, which are explored in detail. It would also represent a scenario that, taking account of New Zealand's current emissions profile, would represent deeper and more ambitious reductions than have been considered in most international studies, as well as in studies of New Zealand's emission reduction potential. Nonetheless, as interest around the implications of the Paris Agreement's 1.5°C temperature goal grows – the IPCC will report in 2018 on the global GHG emission pathways needed to limit global warming to 1.5°C above pre-industrial levels – more detailed analysis of this and similar scenarios that deliver net zero emissions for New Zealand by 2050 may well be warranted.

5 Conclusions and recommendations

Scenario analysis is an invaluable tool in planning for an uncertain future. By developing internally consistent scenarios of how the future might evolve, and how policy will affect this evolution, it is possible to identify key strategic pivot points, possible perverse outcomes, and strategies that are robust to uncertainty.

Scenarios present the future as a series of discrete alternatives; in practice there are typically many more variants. While scenario analysis can be invaluable, it is important to stress that, typically, the development of a small number of discrete alternatives will not capture all possible futures – nor is it intended to. Rather the aim is to starkly illuminate key strategic issues and trade-offs. In practice, when seeking to manage these trade-offs, there are a wide range of options available. In many cases, it will be possible to choose between elements of different scenarios.

The possible scenarios and appropriate policy responses will also change over time. The scenarios presented in this report represent an interpretation of the current evidence base on the opportunities available for New Zealand to reduce its emissions, in the context of the current scientific understanding of the possible severity of physical, economic and social impacts of climate change and the current global commitment to addressing it. However, all of these variables are subject to both evolutionary and disruptive change. This calls for regular assessment and adaptive decision-making approaches that can flexibly respond to unforeseeable changes in circumstances.

In using scenario analysis to explore how New Zealand might adjust in order to substantially reduce its domestic emissions, a number of crucial conclusions emerge.

1. **Any pathway to substantially reduce the country's domestic emissions will involve changes to patterns of energy supply and use.** Substantial energy efficiency improvements, moving towards a 100 per cent renewables grid, and electrification of the passenger vehicle fleet will be requirements for almost all countries in moving to a net zero world. For New Zealand the adjustments that need to be made are comparatively small, likely to be low-cost, and/or will help realise substantial co-benefits.

2. **It is possible for New Zealand to move onto a pathway consistent with domestic net zero emissions, but this will require altering its land-use patterns.** Our analysis suggests that maintaining current land-use patterns, even if with optimistic projections for technology development in both the energy and agriculture sectors, will not place the economy on a domestic net zero pathway.

3. **If New Zealand does seek to move its domestic economy onto a net-zero-consistent trajectory, there is a choice between the extent to which it makes use of new technologies and the patterns of land use.** If a slew of new low-emissions technologies become available in both the agriculture and energy sectors, and successfully penetrate the New Zealand economy, then a variety of rural land-use patterns can be sustained. However, to the extent that these technologies do not become available, increasingly aggressive rates of afforestation will be needed. While our choice of scenarios shows this trade-off starkly, in practice a wide range of combinations of technology penetration and afforestation will be consistent with a domestic net zero economy. With some constraints, there will be an opportunity to adjust the rate of afforestation as the pace of new technological development and deployment becomes clearer.

4. **If it chooses to substantially afforest and is fortunate enough to benefit from the extensive deployment of new technologies, then it could be possible for New Zealand to achieve domestic net zero emissions by 2050.** This analysis has not considered this scenario in detail. However, as interest around the implications of the Paris Agreement's 1.5°C temperature goal grows, more detailed analysis of this and similar scenarios that deliver net zero emissions for New Zealand by 2050 may be warranted.

5. **The more New Zealand relies on forestry sequestration to reduce its emissions in the period to 2050, the more it will need to rely on enhanced technologies in the period beyond 2050 to ensure emissions neutrality.** Afforestation represents a relatively low-cost way for New Zealand to reduce its emissions, albeit with a range of other implications, both positive and negative. However, assuming (as our scenarios do) that most of the timber is ultimately harvested, a given amount of land provides only a temporary reduction in emissions, with additional emission reductions possible only through converting further land to forestry. In our Resourceful New Zealand scenario, the amount of land that is generally considered to be socially and politically feasible to convert to forestry is exhausted in 2050, thus eliminating this source of abatement for the period beyond 2050. In this case, further emission reductions will be possible only from the development and deployment of other technologies, including those that are as yet unknown.

From these key conclusions, we also draw a number of key policy conclusions, for further development.

1. **New Zealand should develop a trajectory for emissions price policy values, to factor into all government assessments and analyses, that is consistent with the international evidence on what is required to deliver the objectives of the Paris Agreement.** This will imply significantly higher values than seen in today's market prices and the trajectory of prices will rise over time. The trajectory of these prices will rise over time. By factoring in these emission price policy values, the New Zealand government can substantially reduce the risk that it will make long-lived infrastructure investment decisions that either lock the country into a high-emissions future, or which could be threatened by asset stranding at a later date.

2. **A robust, predictable emissions price is vital in encouraging the private sector to make investments consistent with a low-emissions future.** The precise policy instrument through which this signal is provided – ETS, emissions tax or a hybrid of the two – is of secondary importance. In scenarios that envisage substantial changes to land use, the extension of the emissions price will help promote land-use decisions that take account of the emissions implications of that use.
3. **The emissions price needs to be accompanied by a range of changed market and regulatory arrangements, infrastructure deployment mechanisms, and specific support to address additional barriers and market failures.** Globally, there is increasing recognition that an emissions price needs to be buttressed by a coherent set of other instruments to maximise effectiveness. There are a number of areas where New Zealand's policy suite could be strengthened:
    a. To support energy efficiency – where there is a particularly strong evidence base for a need to complement emissions pricing – an array of policies can be developed including vehicle fuel efficiency standards, standards on lights and appliances, changes to building codes, and targeted support for industrial consumers to improve energy efficiency.
    b. Agreeing on the strategy, and developing the associated regulations and market arrangements, that encourage the roll-out of electric vehicle charging infrastructure. This planning needs to start in the near term.
    c. Although wind and solar are low cost in New Zealand, new measures to encourage investment, beyond the revenues that can be accessed in the existing electricity market, may be needed to achieve high rates of deployment and the strategic location of generation assets. Case studies of market-based mechanisms such as renewables auctions and portfolio standards, increasingly deployed internationally, provide an indication of what works in different contexts and whether it can be transferred to New Zealand. Further work is required to investigate the precise objectives for a new mechanism in New Zealand and key design parameters.
    d. New investment in back-up plant and grid infrastructure is needed to support higher shares of variable renewables. Potential measures to encourage investment include improved market access for demand-side response and an incentive for investment in batteries. Detailed modelling is needed to determine the additional services that are likely to be required to ensure reliability of the New Zealand electricity system.
    e. In the waste sector, regulation of unmanaged facilities and greater use of anaerobic digesters at farm dumps would facilitate improved methane capture. For managed sites, increasing separation at source can help divert biodegradable household waste and construction and development waste from landfill sites.
    f. Reducing emissions in the agricultural sector requires continued support for R&D to enable the technological developments necessary to cut emissions. In addition, government support to overcome coordination problems will also be needed – for instance, to facilitate collaboration on breeding lower-emissions

livestock. There may also be a role for government in disseminating information about new technologies and educating consumers around the use and implications of these technologies.

g. Additional policies may not be required for the forest sector, although applying a floor to the emissions price would encourage investment in forestry as it could other low-emission investments.

4. **Globally, there is a case for further investment in R&D into low-emissions technologies; given the attractiveness of the Innovative scenario, New Zealand might contribute further to this.** It makes most sense for New Zealand to focus on those technologies most critical to its own emissions future and where it is most likely to find comparative advantage. Options for collaborative research and experimentation across government, business and research institutions should be explored, while further international collaboration can facilitate rapid adoption of new approaches in local contexts. While there are considerable resources already devoted to agricultural R&D, the abatement potential from methane vaccines makes this a continued priority and potential area for increased focus.

5. **Political parties should actively seek to identify and articulate areas of common agreement on climate policy, in order to enhance policy coherence and predictability.** Moving to a low-emissions pathway will take many decades and involve large amounts of investment in long-lived infrastructure. The creation of a stable regulatory and policy environment is essential for ensuring that this investment is delivered at low cost. By seeking to explicitly identify and articulate areas of agreement, political parties can play a crucial role in reducing the risks and costs of the transition. This can be supported by forums such as GLOBE-NZ. At the same time, there will always need to be room for informed debate and party differences over the speed and specifics of policy direction.

6. **Independent institutions can help steer New Zealand's low-emissions pathway development.** Building on the recommendation above, an independent statutory climate commission could help anchor expectations regarding the stability of climate policy, just as the Reserve Bank of New Zealand helps to anchor investor expectations regarding price stability. This might include, for instance, identifying expected trajectories for the emission prices to help private-sector investors make informed decisions over long-lived investments that reduce the risk of lock-in to high emissions assets and/or the risk of asset stranding, or identifiying whether there may be tensions between New Zealand's plans to reduce its emissions and other elements of the government's economic development strategy. The body could also provide a platform to support ongoing, more detailed scenario analysis to inform New Zealand's low-emissions pathway planning and support subsequent coordination and implementation. A dedicated body of experts focusing exclusively on climate change and the appropriate policy response can also help facilitate flexible, adaptive decision-making.

7. **Policymaking should adopt a holistic approach including both economic and cultural interests.** While the scenarios in this report have been developed from an economic perspective, New Zealand has a diverse range of cultural interests which should form part of a more holistic approach to policymaking, particularly as it relates to land-use planning. Chief among these considerations are obligations under the Treaty of Waitangi, and to the mana whenua of a specific land area. All stakeholder groups should be taken account of in the designing of policy, including a process of meaningful consultation with iwi and hapū, as per the Treaty's principle of partnership, to acknowledge their interests and aspirations.

8. **There is an important need to upgrade the evidence base to support New Zealand's low-emissions pathway planning.** The most acute needs are for an energy and land system modelling tool(s) that generates bottom-up estimates of abatement opportunities and costs (to complement existing top-down macroeconomic estimates) and of the interactions between sectors (such as the power system implications of electric vehicle uptake, or bioenergy availability given different scenarios for land use and forestry). Specific studies on heat and agriculture would also be valuable:
    a. In relation to buildings and heat, greater evidence on the potential and costs of electric heating technologies across low-, medium- and high-grade heat, and on the costs of a low- or zero-emission homes standard for new-build properties.
    b. In the agriculture sector, further efforts to narrow the cost ranges on key abatement options by exploring costs in specific contexts within New Zealand.

9. **A particularly important area for further research and policy development is understanding and addressing the distributional implications of differing low-emissions scenarios, and the policy responses that might help alleviate any concerns.** The transition to a low-emissions future provides a wide range of exciting opportunities to reduce New Zealand's emissions in a way that, in aggregate, supports diversified economic activity and can improve overall living standards. It also carries costs: the price of energy may rise, while changes in land-use patterns could imply significant dislocation in rural communities. Importantly, these costs and benefits may be distributed unevenly across New Zealand society. This analysis has been able to consider these issues at only a very high level. Future work is needed to understand in more detail the distributional implications of different scenarios, including impacts on Māori communities given the large changes envisaged to the rural economy. It should also focus on how any negative impacts on vulnerable communities and households can be best addressed. International experience points to a range of strategies that can be used effectively, including social transfers through the welfare system; increasing skills and re-training; and targeting interventions such as improvements to the energy efficiency performance of the housing stock towards the most vulnerable. The robustness of these approaches to the high emissions prices and significant changes envisaged within some of our scenarios needs particular attention.

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