Improving Emission Pricing In New Zealand

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CONTENTS

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Anything you can do, I can do better.
I can do anything better than you.
No, you can't. Yes, I can.
No, you can't. Yes, I can.
No, you can't. Yes, I can, yes, I can!
From "Annie Get Your Gun"

EXECUTIVE SUMMARY

Under the 2015 Paris Agreement, New Zealand has committed to join with other countries in reaching net zero global greenhouse gas (GHG) emissions during the second half of the century. A 2016 study from Vivid Economics commissioned by GLOBE-NZ[1] found that New Zealand's transition to domestic emissions neutrality will require an ambitious combination of efficiency gains in current practice, uptake of new technologies (especially in energy and agriculture) and changes in land use. The authors recommended that emission pricing would be essential to incentivise low-emission investment, and indicated that the choice of instrument was "of secondary importance." This paper considers how New Zealand might achieve more effective emission pricing by either (a) reforming the New Zealand Emissions Trading Scheme (NZ ETS), (b) replacing the NZ ETS with a carbon tax, or (c) complementing the NZ ETS with a carbon tax.

Emission pricing can be a powerful tool for correcting the market failures incentivising human-induced climate change. Emission pricing instruments raise the relative cost of high-emitting goods and services and make low-emission behaviour more competitive. Depending on design, emission pricing instruments can also raise government revenue which can be recycled strategically back into the economy. Emission pricing is essential but by itself insufficient to drive low-emission transformation. The drivers of climate change are complex, and a range of government policy interventions as well as strategic actions by businesses and households will be necessary to address both price and non-price barriers to technology uptake and behaviour change.

Both carbon taxes and emissions trading systems (ETS) can be used to introduce an emission price into market activity to change behaviour. In their pure forms, a carbon tax sets the emission price and leaves it to the market to decide the quantity of emissions, whereas an ETS fixes the quantity of emissions and leaves it to the market to decide the emission price. With both instruments, decision makers face comparable challenges when setting policy for the scope of coverage, point of obligation, mitigation of potential emissions leakage by trade-exposed producers facing a higher price than overseas competitors, collection and redistribution of government revenue, aligning emission pricing and other policies to avoid perverse outcomes, and providing transitional support to vulnerable households, communities and businesses. In both cases, efficient low-emission investment requires predictable and rising long-term price signals, which makes both instruments equally vulnerable to policy uncertainty

[1] GLOBE-NZ is a cross-party group of Members of Parliament whose purpose is to inform participating members on global environmental issues, particularly climate change. It operates as a chapter of GLOBE-International. As of August 2017, GLOBE-NZ had about 35 members representing all seven political parties.

and political volatility. The past political and economic debates have tended to obscure how much both instruments have in common.

Under perfect information, both instruments could be designed to deliver the same outcomes for emission quantity and price. Under uncertainty, outcomes can differ markedly. A popular belief is that a carbon tax provides greater investment certainty than an ETS because the level of a carbon tax is fixed in statute; however, certainty of near-term price does not translate into certainty of behavioural response or long-term return on investment. Given slow legislative processes, the fixed nature of a carbon tax can become a source of risk under unpredictable changes to market conditions. In contrast, ETS prices adjust automatically under changing market conditions to deliver the desired emission outcome. An ETS provides visible signals about market expectations for future prices and the future costs of emitting. The fact that an ETS price responds to expectations about future conditions can be a strength when the market has genuine new information, and counterproductive when the market responds to volatile beliefs about political intentions. In an ETS, banking adds flexibility for managing the timing of compliance.

A carbon tax may be preferable to an ETS in three particular circumstances: when a desired emission price is known (e.g. for alignment with trading partners); when emission price outcomes are more important than emission quantity outcomes under uncertainty; and when a jurisdiction cannot operate an effective trading market that sets an efficient price. Another distinction is that a carbon tax does not limit how far emissions can fall in response, whereas an ETS will not lower emissions beyond the sum of the cap plus banking because reductions in one part of the cap will be offset by increases elsewhere under the cap. If emissions by covered sectors were to fall below the level of the ETS cap, the ETS would not be the cause.

Decision makers can use hybrid instruments to balance risks between emission quantity and emission price outcomes. For example, an ETS can operate with a "price band" mechanism (e.g. a price floor and price ceiling) that adjusts unit supply to avoid undesirable price extremes in both directions. The narrower the band, the closer the ETS becomes to a tax. Under hybrid approaches, the design differences between a carbon tax and an ETS can become less material or even insignificant.

New Zealand's consideration of GHG emission pricing dates back to the 1990s, and the policy-making process has passed through several cycles of debate about the relative merits of carbon taxes versus emissions trading. In 2002, the Labour-led government proposed a carbon tax to take effect from 2008, but abandoned this approach in 2005 due to loss of political support. After a policy review and consultation process, the Labour-led government proceeded with the design and implementation of an economy-wide ETS which took effect from 2008. The National-led government elected in late 2008 retained the ETS but with substantial amendments in 2009, 2012 and 2015. As of mid-2017, political parties, interest groups and the general public have a range of views about whether to reform or replace the NZ ETS.

Although the NZ ETS offers a structural foundation for long-term emission pricing to support decarbonisation, to date the system has had no substantial impact on domestic emissions or business decisions. The causes for this are specific and well-understood. First, under the combination of unlimited access to low-cost overseas units and a half-price unit obligation for non-forestry sectors, the domestic emission price has been too low to incentivise change. Second, since late-2012, participants have had no certainty on future unit supply and price management or on future forestry accounting rules, and therefore no credible long-term price signals to drive transformational low-emission investment.

Subsequent steps have been taken to adjust the design of the NZ ETS. Since mid-2015, international units have been excluded due to de-linking from the Kyoto market. In mid-2016, the government announced the progressive phase-out of the one-for-two unit obligation in non-forestry sectors by 1 January 2019. In mid-2017, the government announced four in-principle decisions: the introduction of auctioning under an overall limit (or cap) by 2021; a quantity limit on the future use of international units purchased by participants (when that becomes feasible); a change to the price ceiling; and coordination of future decisions on unit supply and price management, which are to be made five years in advance and updated on a rolling basis.

To address the current shortcomings and emerging risks in the NZ ETS, the government will need to go further and faster. Additional improvements to the NZ ETS for government to consider include introducing the initial fixed five-year cap as soon as possible and fully fixing future caps five years in advance, introducing a rising price floor to guarantee minimum returns to low-emission investors, placing both the price floor and price ceiling under the cap to manage target and fiscal risk, developing indicative ten-year trajectories for future cap and price settings to extend the investment horizon, requiring participants' use of international units to displace other supply under the cap, and enlisting independent advice. Introducing such changes earlier than 2021 could reduce the emission, economic, fiscal and investment risks from extended policy uncertainty.

Strategic design changes to the NZ ETS will give government the means to raise emission pricing ambition in line with New Zealand's international targets and long-term domestic decarbonisation objectives. However, the ultimate outcomes will depend on political will when deciding the actual limits on unit supply, price management and use of international units.

As one alternative to reforming the NZ ETS, the government could replace it with a broad carbon tax. In designing such a carbon tax, the government could adopt or change the existing NZ ETS settings regarding the scope of coverage; point of obligation; and requirements for measurement, monitoring, reporting and verification. New policy would need to address setting and updating the level of the carbon tax, managing the disposition of banked units held by participants, implementing an alternative regime for managing emissions and removals from forests and industrial removal activities registered in the NZ ETS, mitigating leakage potential for trade-exposed producers, adjusting systems for non-compliance and enforcement, and avoiding perverse outcomes in the transition between systems.

As a second alternative, the government could complement the NZ ETS with a carbon tax that (a) applied to all ETS participants, (b) applied to a subset of ETS participants, or (c) applied to non-ETS sectors (e.g. biological emissions from agriculture). The intended objectives sought through these changes could also be achieved through direct NZ ETS design adjustments or regulations instead of adding a tax. Importantly, neither option (a) nor (b) would produce a further GHG emission benefit beyond the ETS cap. Option (a) would serve the same purpose as an ETS price floor but introduce complexity and uncertainty from managing a separate legislative instrument. Option (b) would reduce the overall cost-effectiveness of reducing emissions across the system but could perhaps generate other benefits. It could also raise equity considerations. If the goal was to accelerate adoption of new technology or practices among a subset of participants, this could also be achieved under the NZ ETS by introducing targeted regulations and adjusting the cap downward. In the case of option (c), policy makers would face similar challenges in designing a carbon tax for the agriculture sector as they would for extending the NZ ETS. If the policy objective was to apply a different price to the agriculture sector, this could also be accomplished within the NZ ETS through free allocation, a progressive obligation or a change in the metric applied to biological emissions.

The chief barrier to effective emission pricing in New Zealand has been a lack of cross-party and public consensus on the desired ambition and pace for reducing New Zealand's domestic emissions. With this barrier remedied, either a reformed NZ ETS or a well-designed carbon tax could support New Zealand's low-emission transition. Under both instruments, government and participants would benefit from better information regarding New Zealand's technical and economic mitigation potential in non-priced sectors, tools to address non-price barriers to mitigation, and opportunities to access high-integrity international emission reductions. Both systems would need to be positioned strategically within a broader and coordinated climate change policy portfolio to help deliver on New Zealand's targets.

Importantly, the availability of practical solutions for managing unit supply and prices under the NZ ETS – many of which are already underway – means that we do not have to change instruments to change outcomes. Whereas an effective carbon tax could take time to design and implement, the fundamental architecture for an ETS is already in place and the market is functioning appropriately. Businesses have already invested substantially in the assets and systems created by the ETS and transitioning abruptly would come at a high cost and further erode business trust in government rulemaking. Given the nature of the emission targets and information that we currently have, the government may find it preferable to set an ETS cap that aligns with an intended domestic share of our Paris target and operates with safeguards against unacceptable price extremes than to select a single carbon tax level and carry all of the associated target performance risk. In this context, a reformed ETS would offer a more effective (and more readily available) tool set for delivering on New Zealand's international targets and domestic decarbonisation under uncertainty than a carbon tax.

INTRODUCTION

1.1. NEW ZEALAND'S CLIMATE CHANGE CHALLENGE

Under the 2015 Paris Agreement, New Zealand has committed to join with other countries in limiting global temperature rises to well below 2°C above pre-industrial levels and striving to limit the temperature increase to 1.5°C above pre-industrial levels. To accomplish this, countries are to achieve global peaking of greenhouse gas (GHG) emissions as soon as possible and net zero global emissions[2] in the second half of the century (UNFCCC 2015).

Because long-lived GHGs accumulate in the atmosphere, urgent action is required globally in order to keep this temperature goal within reach. Under current settings, cumulative emissions will exceed the threshold for 1.5°C within four years, and for 2°C within 15-20 years.[3] Peaking of global emissions by

[2] This is described in the Paris Agreement as "a balance between anthropogenic emissions by sources and removals by sinks."

[3] This provides a 66% chance of achieving the temperature goal.

2020 would buy time for more gradual decarbonisation (Carbon Brief 2017; Carbon Tracker Initiative et al. 2017).

Alongside the global temperature goal, New Zealand has committed to reduce its net emissions to 30% below 2005 gross emissions[4] by 2030 (New Zealand Government 2016).[5] New Zealand will be accountable for its cumulative net emissions over the 2021-2030 period. This target is referred to as New Zealand's Nationally Determined Contribution (NDC). New Zealand's gross and net emissions are currently on a growth trajectory (Ministry for the Environment 2015). In mid-2017, the government projected a target emission budget over the 2021-2030 period of 594 Mt CO_2eq[6] and gross emissions of 814 Mt CO_2eq, leaving a target gap of 220 Mt CO_2eq (Ministry for the Environment 2017).

The government plans to bridge the target gap through some combination of domestic emission reductions, domestic forestry activities and participation in international carbon markets (Ministry for the Environment 2016a). Modelling suggests that even at an emission price of NZ$300 per tonne, New Zealand could not achieve its 2030 target through domestic action alone. At a global emission price of NZ$50, New Zealand could need to bridge up to 80% of the gap through international purchasing (Infometrics 2015). Importantly, this modelling has some transparent limitations and does not provide a definitive assessment of New Zealand's cost-effective domestic mitigation potential through 2030.[7] As of August 2017, no information is readily available in the public domain on the government's assessment of projected net forestry removals under New Zealand's new forestry accounting methodology which will apply to its target over 2021-2030.[8] As a point of reference, the government reported that purchasing 150 million tonnes of international emission reductions at NZ$25-50 per tonne could cost from NZ$3.5 billion to NZ$7.5 billion over the target period (Ministry for the Environment 2016b).

New Zealand is not yet on a pathway toward net zero domestic emissions. Decision makers will need to weigh carefully the balance of investment between overseas mitigation which may cost less per tonne in the near term, and domestic mitigation which offers a longer-term payback and domestic co-benefits as New Zealand moves toward net zero domestic emissions.

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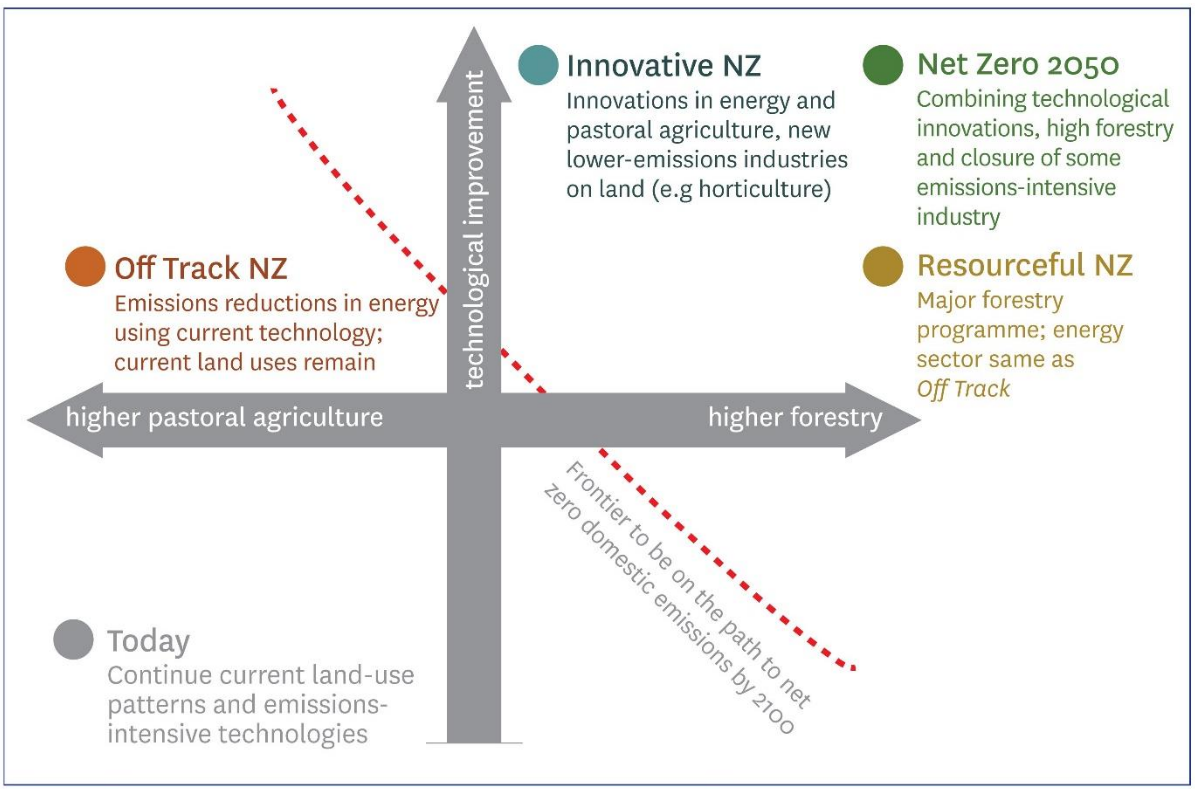
[4] Gross emissions exclude the forestry sector, and net emissions include the forestry sector.
[5] Under the 1990-2015 national GHG inventory, this target equates to a reduction in net emissions of 10.6% below 1990 gross emission levels by 2030.
[6] This is provisional. The government has not yet submitted its final target budget to the UNFCCC Secretariat.
[7] The modelling assumed no technology transformation, no mitigation beyond business-as-usual in the forestry and agriculture sectors, the continuation of current elasticities for the economy's response to a rising price on emissions, and a global emission price of NZ$50 per tonne in 2030 which is well below international price pathways consistent with the global temperature goal. A further consideration is that international carbon market mechanisms under the Paris Agreement are only at a very early stage of development.
[8] The New Zealand government stipulated its preferred forestry accounting methodology for the 2021-2030 period in the submission of its Nationally Determined Contribution. The government has reserved the right to adjust that methodology without reducing target ambition. For example, it could choose to adopt the post-2030 international rule set which has yet to be negotiated (New Zealand Government 2016).

1.2. NEW ZEALAND'S LOW-EMISSION TRANSFORMATION: KEY FINDINGS FROM THE VIVID ECONOMICS REPORT

In 2016, GLOBE-NZ commissioned a study of New Zealand's low-emission pathway options by the London-based consultancy Vivid Economics. The report, entitled *Net Zero in New Zealand: Scenarios to Achieve Domestic Emissions Neutrality in the Second Half of the Century,* found that for New Zealand, an effective transition to emissions neutrality lies within reach. However, it will require more than efficiency gains in current practice – it will also require changes in land use. Pathways relying less on breakthrough technologies in energy and agriculture will require more extensive afforestation by 2050. Further sequestration gains from afforestation can be expected to decline later in the century, meaning alternative emission reduction strategies will be needed in the long term (Vivid Economics 2017a, 2017b).

The report detailed three main scenarios (Off Track NZ, Innovative NZ and Resourceful NZ) illustrated in Figure 1. It could be possible for New Zealand to reach net zero emissions by 2050 by combining high uptake of technological innovation with switching to less emissions-intensive agricultural production, high levels of afforestation, and closure of some emissions-intensive industries (iron and steel, refineries and aluminium).

FIGURE 1: SCENARIOS DIFFER BY THE LEVEL OF TECHNOLOGICAL PROGRESS AND LAND-USE PATTERNS



Source: Vivid Economics (2017a)

Business-as-usual policy and action will not deliver any of the Paris-consistent scenarios in the report. Based on its extensive analysis, Vivid Economics provided a series of high-level policy conclusions for further development. Three of these relate to the strategic use of emission pricing to support New Zealand's low-emission transition:

1. Developing a trajectory for emission price policy values consistent with the Paris Agreement which are applied to all government assessments and analyses to help avoid infrastructure lock-in and stranded assets
2. Providing "a robust and predictable emissions price" that encourages the private sector to make low-emission investments; extending this to biological emissions from the agriculture sector would incentivise less emissions-intensive land uses
3. Combining emissions pricing with "a range of changed market and regulatory arrangements, infrastructure deployment mechanisms, and specific support to address additional barriers and market failures."

With regard to the second recommendation above, the authors elaborate as follows: "The precise policy instrument through which this signal is provided – ETS, emissions tax or a hybrid of the two – is of secondary importance."

Other recommendations reinforce the value of investment in research and development, cross-party support enabling policy coherence and predictability, and use of independent institutions to enhance decision making and engagement.

1.3. PURPOSE OF THIS PAPER

Using the emission pricing recommendations from Vivid Economics as a starting point, this paper considers the use of emissions trading and/or carbon taxes as instruments for achieving "a robust and predictable emission price" in the New Zealand context. This paper does not recommend the level of emission price ambition, which is ultimately a political judgment.

The paper starts by placing emission pricing instruments in a broader policy context for climate change mitigation. It then compares emissions trading and carbon taxes and provides international examples of their current application. After a brief account of New Zealand's past experience with first a carbon tax and then emissions trading, it provides a comparative assessment of three high-level options for the future direction of emission pricing:

1. Reforming unit supply and price settings in the NZ ETS
2. Replacing the NZ ETS with a carbon tax
3. Complementing the NZ ETS with a carbon tax.

The paper concludes with recommendations for future policy making.

2. THE BASICS OF EMISSION PRICING

2.1. POLICY FRAMEWORK FOR CLIMATE CHANGE MITIGATION

In its Fifth Assessment Report (AR5, Kolstad et al. 2014), the IPCC offers a typology for climate change mitigation policies which builds on terms defined in the Fourth Assessment Report (AR4, Gupta et al.

2007). The table below combines information from the two reports. The IPCC also recognises that non-climate policies – for example targeting energy production or consumption or land use – can impact on GHG emissions.

The drivers of climate change are complex and a portfolio of policy instruments will be needed to drive transformational change across the economy. A challenge for decision makers lies in selecting the most effective instruments for each outcome sought, and coordinating the use of multiple instruments to ensure they are cohesive and complementary rather than counterproductive. The IPCC authors concluded, "Economic instruments will tend to be more cost-effective than regulatory interventions and may be less susceptible to rent-seeking by interest groups. The empirical evidence is that economic instruments have, on the whole, performed better than regulatory instruments, but that in many cases improvements could have been made through better policy design." They also suggested that regulatory approaches "will tend to be more suitable in circumstances where the reach or effectiveness of market-based instruments is constrained because of institutional factors" (Kolstad et al. 2014). This finding is reinforced by Schmalensee and Stavins (2017), who reported that "Market-based approaches tend to equate marginal abatement costs rather than emissions levels or rates across sources. This means that in theory, market-based approaches can achieve aggregate pollution control targets at minimum cost." A useful discussion of the advantages and disadvantages of different types of policy interventions is provided by New Zealand Productivity Commission (2017).

TABLE 1: IPCC TYPOLOGY FOR CLIMATE CHANGE MITIGATION POLICIES

Type of policy instrument (AR5)	Definition (AR4)
1. Economic incentives a. Emissions taxes and permit trading b. Subsidies	Taxes and Charges: "A levy imposed on each unit of undesirable activity by a source." Tradable Permits: "These are also known as marketable permits or cap-and-trade systems. This instrument establishes a limit on aggregate emissions by specified sources, requires each source to hold permits equal to its actual emissions and allows permits to be traded among sources." Subsidies and Incentives: "Direct payments, tax reductions, price supports or the equivalent thereof from a government to an entity for implementing a practice or performing a specified action."
2. Direct regulatory approaches a. Performance standards (for processes or activities) b. Technology standards c. Product standards	Regulations and Standards: "These specify the abatement technologies (technology standard) or minimum requirements for pollution output (performance standard) that are necessary for reducing emissions."
3. Information programmes	Information Instruments: "Required public disclosure of environmentally related information, generally by industry to consumers. These include labelling programmes and rating and certification systems."
4. Government provision of public goods and services, and procurement	Research and Development (R&D): "Activities that involve direct government funding and investment aimed at generating innovative approaches to mitigation and/or the physical and social infrastructure

Type of policy instrument (AR5)	Definition (AR4)
a. Directly reducing GHG emissions b. Promoting R&D c. Removing legal barriers	to reduce emissions. Examples of these are prizes and incentives for technological advances."
5. Voluntary actions	Voluntary Agreements: "An agreement between a government authority and one or more private parties with the aim of achieving environmental objectives or improving environmental performance beyond compliance to regulated obligations. Not all VAs are truly voluntary; some include rewards and/or penalties associated with participating in the agreement or achieving the commitments."[9]

Source: Adapted from Kolstad et al. (2014) and Gupta et al. (2007).

2.2. ROLE OF EMISSION PRICING IN LOW-EMISSION TRANSFORMATION

Human-induced GHG emissions are the product of economic activity. Whereas the benefits from emitting activities accrue to producers, consumers and investors, the environmental costs of those emissions are borne globally and across generations. Similarly, the public-good benefits from undertaking activities that remove, reduce or avoid GHG emissions accrue globally and across generations, rather than to those shouldering the costs of such activities. British economist Sir Nicholas Stern characterised climate change as "the greatest and widest-ranging market failure ever seen" (Stern 2007).

Government policy instruments that place a price on GHG emissions create market-based incentives for producers, consumers and investors to choose less emissions-intensive alternatives. Making climate-friendly actions more profitable can enable low-emission innovators to remain competitive and hence help unlock transformational investment. Emission pricing instruments can also generate revenue for government which can be recycled to the economy or society in beneficial ways.

The effectiveness of emission pricing in supporting long-term emission reduction targets depends not only on the current level of the price but also on other factors such as expectations for future emission prices; compliance with emissions monitoring, reporting and verification requirements; policy certainty about government's commitment to emission pricing; price pass-through in the economy; interactions between emission pricing and other policies; other economic drivers such as changing commodity prices and consumer demand; and non-price barriers to behaviour change. Emission price responsiveness will vary by country, sector, activity and actor. Given the complexity of emission reduction drivers and barriers, emission pricing is essential but by itself insufficient to drive low-emission transformation.

[9] "Voluntary Agreements (VAs) should not be confused with voluntary actions which are undertaken by government agencies at the subnational level, corporations, NGOs and other organisations independent of national government authorities."

2.3. COMPARING CARBON TAXES AND EMISSIONS TRADING SYSTEMS

Carbon taxes[10] and emissions trading systems (ETS) aim to achieve the same type of outcome – an economically efficient price signal to reduce emissions – from different directions. In their pure forms, a carbon tax sets the emission price and leaves it to the market to decide the quantity of emissions. An ETS fixes the quantity of emissions and leaves it to the market to decide the emission price. Here is how they work in more detail.

Under a carbon tax, obligated parties must pay a specified levy to the government for each tonne of emissions for which they are liable. This makes it cost-effective for them to invest in reducing or avoiding their own emissions up to the price per tonne they would otherwise face from the carbon tax.

Under an ETS, obligated parties must surrender a tradable emission unit for each tonne of emissions for which they are liable. The government limits the supply of emission units into a trading market which then sets the price based on unit supply and demand. Each tonne of emissions carries the price of surrendering an emission unit, creating an incentive to reduce or avoid emissions up to that price. In a generic ETS, participants can potentially acquire eligible emission units to meet their obligations by:

- Receiving them for free[11]
- Buying them at auction (which generates government revenue)
- Buying them from other participants (which creates incentives for others to reduce their emissions and sell surplus units)
- Earning them by ETS removal activities (such as forestry)
- Buying them from external offset mechanisms (domestic or international).

Debates on the relative merits of emission pricing instruments have been contentious among economists and politicians alike. Such debates tend to obscure the fact that a carbon tax and an ETS have a great deal in common. Goulder and Schein (2013) concluded that "the design of the instrument may be as important as the choice between instruments."

For example, under both instruments:

1. The relative costs of higher-emitting products, services and activities increase across the supply chain, influencing choices by producers, consumers and investors
2. The government needs to decide the scope of coverage, including sectors, gases, activities and entities[12]

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[10] In this paper, the term "carbon tax" refers to the application of a levy to GHG emissions. The latter could include carbon dioxide (CO_2) as well as other gases such as methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). This paper applies the assumption that a carbon tax and an ETS could cover the same set of GHGs, sectors, activities and participants.

[11] Surrendering emission units comes with an opportunity cost that preserves the incentive to reduce emissions even when the units are allocated for free.

[12] In an ETS, a price signal can be applied to both emissions and removals (e.g. from forestry, industrial activities or carbon capture and storage) through the one mechanism. A carbon tax is applied to emissions, not to removals,

3. The government needs to decide where in the supply chain to place the obligations for reporting emissions and either paying the tax or surrendering the emission units
4. In the case of trade-exposed producers, there is potential for emissions leakage if local production subject to the emission price merely shifts to other jurisdictions that do not impose a comparable regulatory pressure on emissions (whether from a pricing instrument, regulations or other means)
5. Mechanisms are available to reduce the risks of emissions leakage[13] (and the level of price protection offered to trade-exposed producers is likely to be politically contentious)
6. It is possible to link emission pricing to a separate offsets crediting or subsidy mechanism
7. The government needs effective monitoring, reporting, verification, non-compliance and enforcement systems and both regulators and participants need to have the capacity to fulfil their obligations (such systems may even be identical for both instruments)
8. The government earns revenue, either from the carbon tax or from auctioning emission units, which can be returned to the economy or society in some form (e.g. reduction in distortionary taxes, investment in specific initiatives, or transitional support to vulnerable households, communities and businesses)
9. The amount of revenue gained by government will be subject to uncertainty because of other economic, technological and social drivers of emissions (e.g. changes in international commodity prices or technology uptake)
10. The government needs to manage interactions between emission pricing and other policies to guard against perverse outcomes (e.g., disproportionate impacts on vulnerable households, communities and businesses).

For both instruments, a key consideration is that low-emission investment in long-lived technology and infrastructure will be driven by market expectations for long-term emission prices and deterred by policy uncertainty. Policy uncertainty about the government's emission pricing commitment and ambition over the longer term can undermine the effectiveness of both instruments. For efficient low-emission investment to occur under either instrument, the targeted emission price will need to change in a predictable way over time to support domestic decarbonisation in line with the global temperature goal.

Important differences between the instruments relate to administrative complexity, potential for price volatility, the management of uncertainty, interactions with other climate change policies and the potential for linkages across different jurisdictions (Goulder and Schein 2013). The management of uncertainty can be a key area of concern when choosing between instruments. A common belief is that the emission price under a carbon tax is more predictable – and therefore offers greater investment certainty – than under an ETS. This may be true in the near term – particularly while the current

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but it can operate in conjunction with a separate subsidy or crediting system that creates price incentives for removal activities.

[13] In the case of an ETS, the most common mechanism to guard against leakage is free allocation of emission units. Under a carbon tax, exemptions or rebates can be used. Under both mechanisms, other transitional assistance can be provided to ease the introduction of emission pricing.

government remains in place – because the level of a carbon tax is fixed in statute whereas the price in an ETS varies with supply and demand in the market. Unlike a carbon tax, an ETS can involve price volatility. However, a certain near-term price under a carbon tax does not translate automatically into certainty of behavioural response or long-term return on investment. In the longer term, both instruments:

1. Operate under unpredictable market conditions in a constantly evolving national and international context (environmental, economic, technological and social)
2. Are vulnerable to political volatility
3. Are subject to uncertain and/or variable emission price sensitivities across the economy
4. Can be affected by interactions with other policies.

If we operated in a world with perfect information, then it would be possible to achieve identical emission quantity and price outcomes using either a carbon tax or an ETS, and the optimal outcome would balance the social marginal costs of the system with the social marginal benefits of reducing, avoiding or removing emissions (Sin, Kerr, and Hendy 2005). In the absence of perfect information and in their pure forms, an ETS offers less emission price certainty and greater certainty on emission outcomes than a carbon tax. An ETS is better able to adjust emission prices quickly to changes in market conditions, like commodity prices, technology costs or consumer demand. The fact that an ETS price responds to expectations about future conditions can be a strength when the market has genuine new information, and counterproductive when the market responds to volatile beliefs about political intentions. Through banking, an ETS offers greater flexibility about when emission reductions occur within the system, encouraging the market to deliver least-cost emission reductions over time.

At a high level, a carbon tax may be preferable to an ETS in three particular circumstances:

1. When a desired emission price is known[14]
2. When emission price outcomes are more important than emission quantity outcomes given the nature and distribution of costs, benefits and risks under uncertainty
3. When a jurisdiction cannot operate an effective trading market that sets an efficient price (e.g. due to existing market structures and practices, low government capacity to oversee the market, low participant capacity to engage in trading activity, potential for uneven market power or corruption, etc.).

Over a long period of time as we move toward net zero emissions, it is unclear whether a series of taxes or a series of emission caps (with banking) will lead to a more cost-effective transition path. Sin, Kerr, and Hendy (2005) discuss how the efficiency of outcomes from a carbon tax can compare to that from an ETS depending on whether the benefits of mitigation are assessed relative to the cost of buying

[14] For example, this could occur if one jurisdiction wished to harmonise its emission price with that of a trading partner.

international units or the cost of damages (direct and indirect) from New Zealand's emissions. Further discussion of these issues from a standpoint of economic theory is beyond the scope of this paper.

Importantly, an ETS will stop emissions from rising above a target level, whereas a carbon tax could allow emissions to exceed the target level. However, an ETS will not lower net emissions beyond the sum of the cap plus banking because reductions in one part of the cap will be offset by increases elsewhere under the cap. If emissions by covered sectors were to fall below the level of the ETS cap, the ETS would not be the cause. In contrast, a carbon tax does not limit how far emissions can fall in response (Goulder and Schein 2013). These design differences are less material in the context where the cap under an ETS and the price under a carbon tax can be adjusted over time – which is likely to be the case.

Both carbon taxes and ETS pose risks that need to be managed carefully by decision makers. In the case of a carbon tax, the key risk is that the level of the tax will deliver emission outcomes that are too low or too high relative to target obligations or the broader benefits of mitigation. In the case of an ETS, the key risk is that the supply constraint will impose costs on the economy that are too low to drive efficient behaviour change or so high that they exceed the benefits of mitigation. In both cases, the social and political acceptability of outcomes for both emission quantity and price will determine the durability of emission pricing. Unpredictable changes to emission pricing instruments in response to economic or political volatility can undermine market confidence and deter efficient low-emission investment.

Policy makers have to navigate by the two stars of emission quantity and emission price. For this reason, many jurisdictions have shifted toward hybrid approaches which fall somewhere on the spectrum between a pure price instrument and a pure quantity instrument. In an ETS, adding a "price band" (consisting of a price floor and/or price ceiling) allows unit supply to be adjusted predictably in response to price, thereby providing a safeguard against price extremes in both directions. If ETS prices rise above the price ceiling, the mitigation price risk is transferred from ETS participants to government. This captures some of the price protection and price predictability benefits of a carbon tax while leaving the market to set the price within the band. While hybrid approaches[15] offer tools for managing quantity and price uncertainty through predictable processes, their operation can also be a source of policy uncertainty. Sin, Kerr, and Hendy (2005) and Goulder and Schein (2013) provide further elaboration on the merits of hybrid approaches.

2.4. INTERACTIONS BETWEEN EMISSION PRICING AND OTHER POLICY INSTRUMENTS

In designing both a carbon tax and an ETS, it is important for policy makers to consider their interactions with other policies, both existing and new. An emission pricing instrument can both affect and be affected by a wide range of other policies. Some of these may be targeted to GHG emissions specifically, while others may relate to achieving broader objectives in areas like renewable energy, energy efficiency, energy security, air and water quality, transport, biodiversity, waste, technology or building standards, economic or social development, or poverty alleviation. It can be useful to conduct a

[15] While an ETS price band is the hybrid option commonly considered, it would also be possible to implement a carbon tax with a "quantity band" (i.e. a desired corridor for emissions) used to trigger tax adjustments.

thorough policy mapping exercise when designing an emission price instrument to identify potential interactions.

From an emissions standpoint, such interactions can be mutually reinforcing, counterproductive or duplicative. For example, policies that remove non-price barriers to behaviour change (e.g. lack of information, limited access to financing or split incentives between landlords or tenants) can make an emission pricing instrument more effective. Regulations that force actions beyond those incentivised by an emission price may become the dominant drivers of behaviour change – and vice versa. A jurisdiction using regulations to drive emission reductions by participants with higher marginal abatement costs may be able to bridge its remaining target gap with a lower emission price.

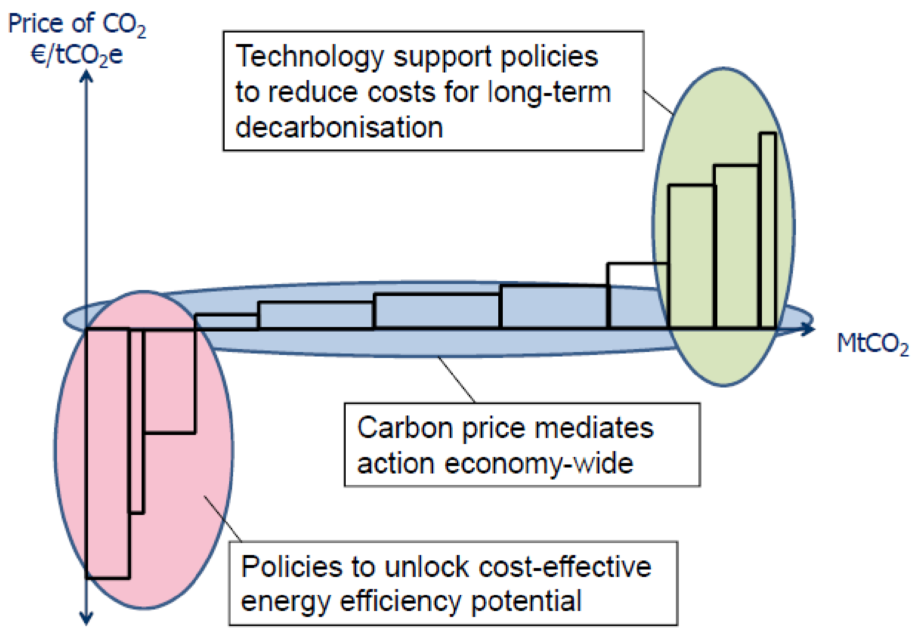
There can be differences in how carbon taxes and ETS interact with other policies. When an additional emission-related regulation, subsidy or tax is applied to a subset of the participants subject to a carbon tax, all participants in the system will continue to face the same carbon tax. Depending on design, it will be possible for the additional policies to achieve emission reductions beyond those resulting from the carbon tax alone. In contrast, when an additional emission-related regulation, subsidy or tax is applied to a subset of ETS participants and the ETS cap remains fixed, that subset will emit less, thereby reducing demand for emission units, lowering emission prices and raising emissions elsewhere under the cap. There will be no further emission benefit beyond the cap – unless the cap itself is subsequently reduced – and effective emission prices will be higher for some participants than others. This could be desirable if it addresses other market failures and produces positive spillover effects. Further discussion of these issues is provided by OECD (2011); Hood (2011, 2013); Goulder and Schein (2013) and Partnership for Market Readiness and International Carbon Action Partnership (2016).

Hood (2011, 2013) recommends that a core policy package for climate change mitigation should include a broad emission price operating alongside (a) energy efficiency policies that overcome non-price barriers to low-cost mitigation, and (b) research, development and demonstration (RD&D) and technology deployment policies to reduce the long-term cost of decarbonisation (see the figure below). According to Hood, this combination helps to:

- Bring forward least-cost mitigation options across sectors to minimise economy-wide costs of decarbonisation
- Encourage technology innovation to lower future mitigation costs
- Maintain flexibility for managing uncertainty.

To be effective, this package needs to be designed in a way to minimise transaction costs, address distributional issues, and maintain acceptable impacts on social welfare (Hood 2011).

FIGURE 2: THE CORE POLICY MIX: A CARBON PRICE, ENERGY EFFICIENCY AND TECHNOLOGY POLICIES



Source: Hood (2011).

In jurisdictions that combine regulations or subsidies with emission pricing, the emission price will not necessarily reflect marginal abatement costs – or the overall level of mitigation effort in that jurisdiction. Therefore, the ambition of emission reduction efforts in different jurisdictions should not be evaluated on the basis of emission prices alone – regardless of whether they are generated by an ETS or carbon tax. Furthermore, the actual effectiveness if an emission price in a given jurisdiction will depend on the removal of non-price barriers to mitigation. A high emission price under an ETS or carbon tax will not achieve an efficient emission level without the removal of non-price barriers and inappropriate subsidies.

An interesting case study is provided by the US state of California, which implemented its ETS within a broad mitigation policy portfolio. Because of the strong regulatory drivers to reduce emissions, the system's ETS price has stayed close to the price floor while emissions have declined. The ETS was intentionally designed as a backstop relative to other policies. It was projected to contribute only 29% of the reductions needed to achieve the state's 2020 target, with the remainder coming from other policies (Environmental Defence Fund, CDC Climat Research, and International Emissions Trading Association 2015).

2.5. INTERNATIONAL EXAMPLES OF EMISSION PRICING

GHG emission pricing is assuming an increasingly prominent role in countries' policy responses to climate change. As of 2017, emission pricing instruments are operating in over 40 national and 25 subnational jurisdictions and cover about 15% of global emissions. Two-thirds of countries are considering some form of emission pricing in their NDCs under the Paris Agreement. A global emission pricing system, CORSIA, has been agreed by the International Civil Aviation Organisation (ICAO) (World Bank and Ecofys 2017).

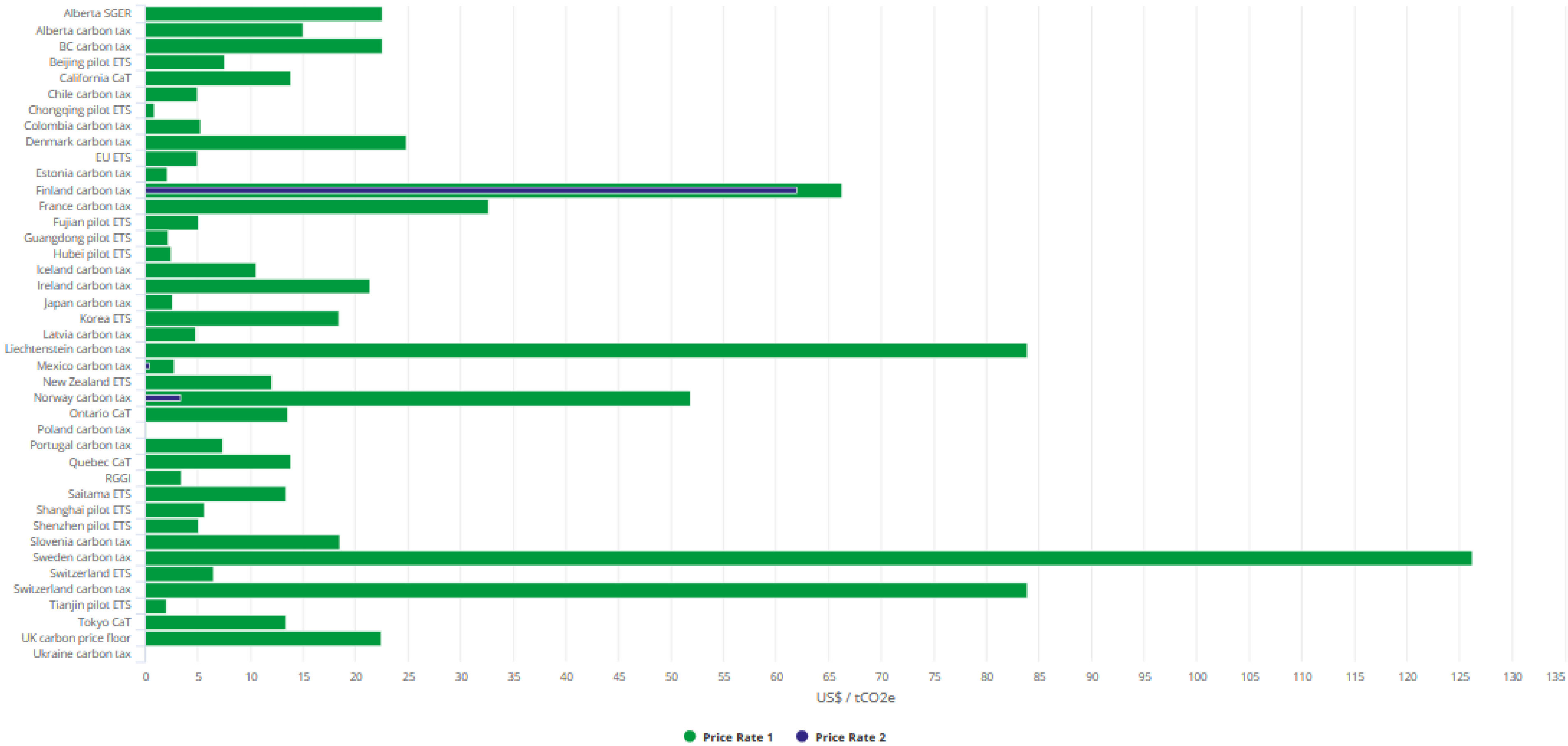
The ambition of emission pricing varies widely across jurisdictions, from a low of less than US$1 per tonne to a high of US$126. About 75% of emissions covered by emission pricing instruments are priced below US$10 per tonne (World Bank and Ecofys 2017). The distribution of emission prices by jurisdiction is presented in the figure below. This illustrates that the emission prices in most jurisdictions currently fall well below levels consistent with the Paris temperature goal[16] or with the social cost of carbon.[17]

Each of these emission pricing systems features characteristics that are uniquely tailored according to the objectives and circumstances of its jurisdiction. Of the 46 emission pricing systems implemented or scheduled as of 2017, half consist of an ETS and half a carbon tax. ETS instruments cover two-thirds of priced emissions (World Bank and Ecofys 2017). A comprehensive analysis of these systems is beyond the scope of this paper. Annex I presents a summary table on emission pricing instruments compiled by the World Bank.

[16] According to a study by the High-Level Commission on Carbon Prices, co-chaired by Sir Nicholas Stern and Joseph Stiglitz, “the explicit carbon-price level consistent with the Paris temperature target is at least US$40–80/t$CO_2$ by 2020 and US$50–100/t$CO_2$ by 2030” provided there is also a broader supportive policy environment (High-Level Commission on Carbon Prices 2017).

[17] The social cost of carbon can be simply described as the benefit to society of avoiding the damages from a tonne of CO_2 emissions. In a study used for policy development by the US Obama administration, assuming a discount rate of 3 per cent, a central value of US$36 applied for 2015, rising to US$42 in 2020, US$50 in 2030 and US$69 in 2050 (based on 2007 dollars) (Interagency Working Group on Social Cost of Greenhouse Gases 2016).

FIGURE 3: PRICES IN CARBON PRICING INITIATIVES SELECTED



Note: Nominal prices on 1 April 2017. This includes systems implemented, scheduled or under consideration. "Prices are not necessarily comparable between carbon pricing initiatives because of differences in the number of sectors covered and allocation methods applied, specific exemptions, and different compensation methods. Due to the dynamic approach to continuously improve data quality and fluctuating exchange rates, data of different years may not always be comparable." Norway applies variable carbon tax rates, with a much higher rate applies to offshore oil production than to domestic use of liquid and gaseous fossil fuels. Finland applies a higher carbon tax to liquid transport fuels than other fossil fuels. Mexico applies a lower tax rate to coal than to other fossil fuels.

Source: World Bank (2017) and (Munoz 2016)

3. A BRIEF HISTORY OF EMISSION PRICING IN NEW ZEALAND

3.1. PREPARATION FOR A CARBON TAX (2002 TO 2005)

New Zealand's consideration of emission pricing began in the 1990s (Rive 2011). In 1999, emissions trading was selected as the preferred option for the first Kyoto commitment period by the National-led government (Hodgson 2005). In 2002, the Labour-led government introduced a comprehensive climate change policy package which included a carbon tax on the energy and industry sectors to be implemented from 2008. It was to have a price ceiling of NZ$25 per tonne, and be set to approximate the international price of emissions. Revenue generated by the tax was to be returned to the economy through the tax system. Exemptions from the tax were offered to "competitiveness at risk" industrial producers in return for entering into a Negotiated Greenhouse Agreement (NGA) to achieve world's best practice in emissions intensity. NGAs were essentially a baseline-and-credit trading mechanism offered as an alternative to the carbon tax. The 2002 policy included an offsets crediting mechanism called Projects to Reduce Emissions (New Zealand Cabinet 2002a, 2002b). Due to the complexity of the policy, only two NGAs were ultimately agreed, and these have been honoured under the NZ ETS.

The government developed the detailed design for the carbon tax and conducted consultation in 2005. Much of this work was carried into the later design of the NZ ETS. The carbon tax was expected to start at NZ$15 per tonne and change over time alongside sustained divergence from international prices up to the level of the price ceiling (Inland Revenue Department 2005). In June 2005, it became evident that New Zealand would be facing a target deficit for the first Kyoto commitment period, although it had anticipated a surplus at the time of ratification. The government launched a review of its climate change policies. Following the 2005 election, the Labour-led government lost sufficient support for the carbon tax from its coalition partners. The carbon tax was abandoned in December 2005 (Leining and Kerr 2016).

3.2. IMPLEMENTATION OF THE NZ ETS (2007 TO 2017)

From 2005 to mid-2007, the government re-assessed its climate change policy options. It consulted on the possibility of a broad ETS, carbon tax or other measures to apply post-2012 (Ministry for the Environment 2006). Finding general support for emissions trading in New Zealand combined with rising international interest in emissions trading and a growing projected Kyoto deficit, the Labour-led government launched design of an ETS in April 2007. The legislation establishing the NZ ETS was passed in September 2008, shortly before an election (Leining and Kerr 2016).

The system was the first in the world designed to cover all sectors of the economy with phased introduction. It also innovated in applying an upstream point of obligation in the energy sectors (a feature of the previous carbon tax), with the option for large fuel users to opt in with an upstream carve-out (Leining, Allan, and Kerr 2017). Influenced by the earlier failure of the carbon tax, the government did not introduce auctioning which would generate government revenue. Instead, the system had unlimited buy-and-sell linkages to the international Kyoto market (although some unit types were not eligible). Essentially, instead of setting an emission cap and emission price of its own, the NZ ETS borrowed the ones offered by the international Kyoto market, ensuring the domestic price would match the international price and avoiding political debates about capping domestic emissions. Initially the system provided fixed pools of free allocation to the forestry, fishing and emissions-intensive, trade-exposed (EITE) industrial sectors. Industrial free allocation was to be provided on an ongoing basis to mitigate leakage; free allocation to the forestry and fishing sectors was to compensate for losses in value and soften the transition to emission pricing and was provided on a one-off basis (although in two tranches in the case of forestry).

In November 2008, an election brought a National-led government to power. Under its confidence-and-supply agreement with the ACT Party, the government immediately implemented a review of the NZ ETS. This led to amendments in 2009 which moderated the price impacts of the system by introducing a one-for-two obligation in non-forestry sectors, introducing a price ceiling of NZ$25 per tonne, and changing to unlimited output-based free allocation to EITE industrial producers. The first two measures were to continue through December 2012. Unit obligations for biological emissions from agriculture, originally scheduled to start in January 2013, were deferred to 2015.

In 2011, the government launched a second review of the NZ ETS as required under legislation. This led to amendments in 2012 which extended the price moderation measures indefinitely, deferred the phase-out of free allocation indefinitely, and deferred unit obligations for biological emissions from agriculture indefinitely.

In late 2012, the government decided to take its international emission reduction commitment for the 2013-2020 period under the UNFCCC rather than the Kyoto Protocol. This led to de-linking the NZ ETS from the Kyoto market in mid-2015. International units have not been accepted in the system since then. By mid-2017, NZU prices had risen to NZ$17-18,[18] having recovered from a low price under linking of NZ$1.45 in February 2013 (Leining 2016; Leining and Kerr 2016; Leining, Ormsby, and Kerr 2017).

Starting in late 2015, the government initiated its third review of the NZ ETS. This was divided into two stages. The first stage resulted in a decision in May 2016 to progressively phase out the one-for-two obligation in non-forestry sectors, so a full obligation will apply from January 2019 (Bennett 2016). Decisions following from the second stage are scheduled to continue through 2018. In July 2017, a series of in-principle decisions on unit supply, price management and linking were announced (Bennett 2017) which are detailed in section 4.2.1.

4. ENABLING A ROBUST AND PREDICTABLE EMISSION PRICE IN NEW ZEALAND

4.1. WHY NEW ZEALAND NEEDS TO RESHAPE ITS APPROACH TO EMISSION PRICING

The NZ ETS has been heavily – and justifiably – criticised for failing to reduce New Zealand's domestic emissions. In its 2016 evaluation of the system, officials acknowledged it has had no impact on domestic emissions or business decisions (Ministry for the Environment 2016c). The primary reasons for this are specific and well understood:

[18] See https://www.commtrade.co.nz/.

1. *Exposing participants to low emission prices.* From 2008 through mid-2015, NZ ETS participants could meet their obligations using unlimited purchases of overseas Kyoto units so the international market set the domestic price. Because of global oversupply and shortcomings in the international rules, overseas Kyoto units came at low cost and with variable (and generally low) environmental integrity. In the 2009 amendments, the government halved the emission obligation for non-forestry sectors. This combination of measures removed the short-term incentive to reduce domestic emissions.
2. *Lack of credible and predictable long-term emission price signals.* Long-term emission price signals are critical to influence low-emission investment, especially in the long-lived technology and infrastructure that will shape New Zealand's decarbonisation pathway. The domestic market has had no indication of long-term unit supply and emission prices since the government first signalled the potential for delinking from the Kyoto market at the end of 2012. Furthermore, the market has faced the possibility of a politically driven change in domestic emission reduction ambition or the emission pricing instrument with every election. Uncertainty over long-term forestry accounting rules has been another barrier to mitigation investment.

Importantly, solutions to these shortcomings are available and, in fact, required. The NZ ETS was initially calibrated for a world which no longer exists (if it ever did): one in which New Zealand could rely on the international market to set an appropriate domestic emission price, and allow its domestic emissions to increase as long as they were offset globally. Under the Paris Agreement, all countries must transition to net zero emissions, there is no integrated carbon market governed by internationally agreed rules, and there is no convergence toward a single efficient global emission price.

Article 6 of the Paris Agreement allows the use of carbon markets to meet NDCs through "internationally transferred mitigation outcomes" (ITMOs). However, there is no top-down framework for such transfers and they must be made from government to government in a way that avoids double counting under the targets of the seller and buyer. ETS linking qualifies under Article 6, but would present significant challenges for New Zealand. For example:

- ETS linking would reduce New Zealand's sovereignty over domestic emissions and emission prices.
- The NZ ETS design is not easily compatible with two-way ETS linking given the characteristics of the other ETS currently operating and planned (Leining, Ormsby, and Kerr 2017).
- Given our target gap, New Zealand would want to link the NZ ETS with a net seller with a stable and well-established ETS, and such systems are yet to emerge.

The Paris Agreement provides for the creation of a new central market mechanism which could be accessible by both government and private entities, but the rules for this are likely to be years away. Global emission prices are likely to remain highly variable in a system where targets and policies are developed from the bottom up.

In a post-Paris world, New Zealand will need to reclaim sovereignty over decisions on unit supply and emission price management in the NZ ETS; it can no longer delegate these decisions overseas. The NZ ETS must be either reformed or replaced if emission pricing is to support the achievement of New Zealand's 2030 target and long-term decarbonisation process.

To place New Zealand on an efficient emission reduction pathway, any emission price instrument – trading or tax – should satisfy the following objectives:

1. Maintain government sovereignty over domestic emissions and emission prices
2. Raise domestic emission price ambition over time in line with New Zealand's international targets and objectives for domestic decarbonisation
3. Improve policy and price predictability to support efficient low-emission investment
4. Distribute emission reduction responsibilities, costs and risks fairly and efficiently across ETS sectors, non-ETS sectors and government/taxpayers
5. Mitigate potential emissions leakage to other jurisdictions
6. Maintain environmental integrity, transparency, compliance and enforcement
7. Manage uncertainties and risks (environmental, economic, fiscal and social)
8. Manage interactions with other policies
9. Raise and manage revenue strategically
10. Achieve broad and enduring public and cross-party acceptance.

4.2. WHERE MIGHT NEW ZEALAND GO NEXT WITH EMISSION PRICING?

4.2.1. REFORM UNIT SUPPLY AND PRICE MANAGEMENT IN THE NZ ETS

The fundamental architecture of the NZ ETS is sound and the market is operating as expected (Ministry for the Environment 2016c). Adapting the NZ ETS to function effectively in the post-Paris context will require feasible changes to policy settings for unit supply, price management and linking to international markets. These changes will be the focus of analysis in this section.[19]

Two initial changes started to shift the NZ ETS in a constructive direction. In mid-2015, the system delinked from the international Kyoto market – a consequence of New Zealand's decision to take its 2013-2020 commitment under the UNFCCC rather than the Kyoto Protocol – and international units have not been accepted for NZ ETS compliance since then. In mid-2016, the government announced it would progressively phase in a full one-for-one unit obligation in non-forestry sectors by 1 January 2019.

In July 2017, the government announced in-principle decisions to change the NZ ETS in four important ways:

1. By 2021, introducing auctioning of emission units under an overall limit (essentially a cap), an option that has been available in legislation since 2012 but not yet implemented

[19] To operate more effectively, the NZ ETS would also benefit from additional improvements in areas such as forestry accounting rules, information sharing, market oversight and second-order operational matters. These considerations are part of the government's 2015-2017 review of the NZ ETS, with decisions expected in mid-2018 (Bennett 2017). Many of these considerations could be relevant to an alternative emission price instrument in New Zealand and they will not be analysed in this paper.

2. Implementing an alternative price ceiling to replace the current fixed-price option of NZ$25 per tonne once auctioning or linking is in place
3. Placing a quantity limit on the use of international units purchased by NZ ETS participants (which is not possible now but could become so in the future) to help meet their obligations
4. Coordinating future decisions on unit supply, the price ceiling and linking, fixing settings five years in advance and updating them on a rolling basis.

The government affirmed it would make no change to the level of free allocation to industrial producers until at least 2021, and that biological emissions from agriculture would remain outside the NZ ETS for the foreseeable future (Bennett 2017).

These four changes will be essential if the NZ ETS is to operate effectively in the future. Auctioning under a binding limit can be used to fill the supply gap created by delinking from international markets, enable scarcity of supply to generate a positive price, and produce valuable revenue which could be recycled into the economy. An alternative price ceiling can allow emission prices to rise in line with New Zealand's domestic emission reduction objectives. A quantity limit on the use of international units by NZ ETS participants can help to ensure some level of domestic emission reductions and limit exposure of the system to international price volatility. Coordinating and updating decision making as proposed can help to improve policy and price certainty. However, the ultimate effectiveness of these changes will depend on the actual settings for auctioning, an emission price ceiling and participants' use of international units; how they interact with other relevant policies in both ETS and non-ETS sectors; and the government's capacity to acquire cost-effective international emission reductions under Article 6 of the Paris Agreement. More detailed decisions on these issues are scheduled to be made by the end of 2018.

Over 2016-2017, Motu Economic and Public Policy Research conducted an ETS Dialogue which brought together diverse experts from government, businesses, NGOs and research organisations to discuss options for reforming the NZ ETS. From that process emerged an integrated proposal for managing NZ ETS unit supply, price management and linking. The proposal was summarised in a paper co-authored by several participants in that process (Kerr et al. 2017).[20] The government's four in-principle decisions described above are fully consistent with the paper's recommendations, but to address the current shortcomings and emerging risks in the NZ ETS, the government will need to go further and faster. Kerr et al. recommend additional changes which would support more effective management of unit supply, prices and linking under uncertainty. These are:

1. *Set an initial fixed five-year cap and fix future caps for a full five years in advance.* Under this model, the rolling year 6 extension would be used to adjust market expectations for long-term supply (the key driver of price), and supply for years 1 through 5 would remain fixed. The government's current model requires initial decisions on auction supply to be made five years in advance but adjustments can be made for years 3 through 5 with advance notice. This contributes to policy uncertainty on near-term supply for market participants.

[20] The paper does not necessarily reflect the views of or endorsement by ETS Dialogue participants, their organisations, or the programme funder (the Aotearoa Foundation).

2. *Add a price floor to be implemented as a reserve price at auction.* Under this mechanism, units that were not sold at auction would be shifted into a unit reserve, thereby reducing domestic supply and offering a form of government banking. A price floor ensures a minimum price will be maintained at auction and market supply adjusted downward in the event of unintended over-allocation, unexpected changes in market conditions, or interactions between the ETS cap and other relevant policies. A price floor gives greater confidence about returns to low-emission investors. Under the proposed design, it would still be possible for units trading in the secondary market to fall below the price floor.
3. *Implement the price floor and price ceiling using a unit reserve under the NZ ETS cap.* The combination of a price floor with a price ceiling would create a "price band" that safeguards against both downside and upside price risk. Importantly, the ETS market would continue to set the emission price within the limits of the price band. The narrower the price band, the closer the system would be to a carbon tax. Placing the price management mechanism within the cap would limit the fiscal risk from the price ceiling, which is an issue in the current design. This would be considered a form of "soft" price protection since the amount of price relief would be limited by the cap.
4. *Add indicative ten-year trajectories to the cap and price band to guide future extensions.* This would impose on government the discipline of forecasting corridors for unit supply and prices, and provide a 15-year horizon to guide ETS participants and investors.
5. *Require participants' use of international units to displace other supply under the cap.* While the government has usefully proposed to limit participants' use of international units, it has signalled the limit could cover up to 100% of the target gap. This provides no certainty on future unit supply or prices in the domestic market and could discourage low-emission investment. Setting a low limit on participants' use of international units and requiring that international units displace other unit supply under the cap would help ensure that participants' international purchasing does not drive New Zealand off its intended domestic decarbonisation pathway.
6. *Enlist independent advice*. Decisions to limit unit supply, prices and linking in an ETS require sound technical information but ultimately are political in nature and should remain with government. Providing for independent expert advice would support evidence-based and transparent decision making which creates a stronger foundation for both public and cross-party acceptance and support.
7. *Introduce auctioning with a price band as soon as possible*. Deferring the implementation of auctioning under a limit and an alternative price ceiling until 2021 extends uncertainty for market participants and investors and increases the risk of stranded assets as well as fiscal risk. Reducing New Zealand's domestic emissions in line with our targets will require emission prices considerably higher than NZ$25 per tonne. Emission prices have risen dramatically in the last few years. As confidence in the future of the ETS grows, they could easily pass $25 per tonne. At this point, participants will choose to bank their NZUs and meet their obligations using the fixed-price option instead. If international emission reductions cost the government more than NZ$25 per tonne, then this will come at a net cost to taxpayers.

If these changes were implemented with cross-party support, the NZ ETS would be empowered to deliver more ambitious emission reductions with greater policy and price predictability and safeguards that balance price risk to participants and fiscal risk to government in the face of uncertainty about New Zealand's actual economic mitigation potential, emission price responsiveness and the supply and cost of high-quality international emission reductions.

A critical consideration which deserves further work is how to balance New Zealand's "emission budget" across ETS and non-ETS sectors taking into account expectations for purchasing of international emission reductions. In the Cabinet paper supporting the July 2017 decisions, the government expressed its intentions to distribute its NDC budget of 594 Mt CO_2eq for the 2021-2030 period as follows:

- Covering the emissions from the non-ETS sectors (dominated by agriculture) projected under current measures (427 Mt CO_2eq)
- Meeting demand for free allocation by industrial producers (123 Mt CO_2eq)
- Auctioning NZUs under the NZ ETS (43 Mt CO_2eq), which could generate revenue ranging from $0.73 billion to $2.15 billion over the period (Ministry for the Environment 2017).

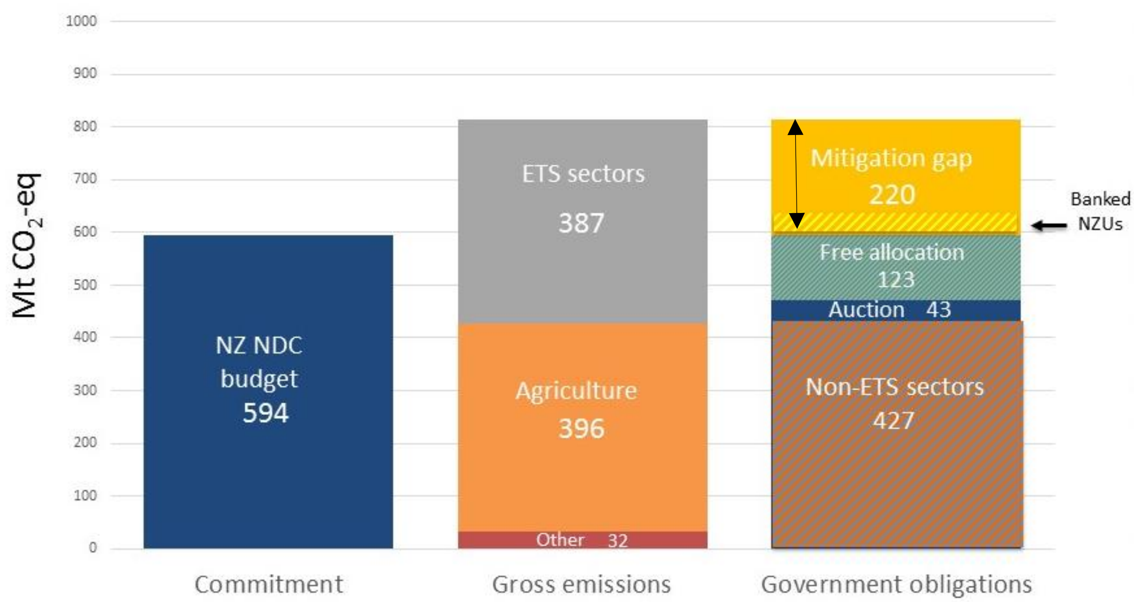
As shown in the figure below, this leaves a mitigation gap of 220 Mt CO_2eq. Furthermore, NZ ETS participants will carry into the Paris period banked NZUs which enable them to emit 51 Mt CO_2eq but are not backed by emission reductions internationally recognised under New Zealand's target.[21] If those units are surrendered in the NZ ETS, the associated emissions will come at a cost to the taxpayer.

Between free allocation, auctioning and banking, NZ ETS participants can expect firm unit supply of approximately 218 Mt CO_2eq over 2021-2030, whereas their projected demand is 387 Mt CO_2eq. Possible options for bridging that gap are:

1. Increasing net forestry removals (whose level is uncertain)
2. Incentivising more ambitious emission reductions in non-ETS sectors, which would enable higher levels of government auctioning (and more government revenue)
3. Government purchasing of international emission reductions, which would enable higher levels of government auctioning (with uncertain implications for government revenue net of purchasing)
4. Participant purchasing of international emission reductions, which could potentially add to NZ ETS unit supply unless it was required to displace other supply (although the feasibility and timing of participant purchasing are highly uncertain)
5. Accelerating the phase-out of free allocation to industrial producers, which would not affect total unit supply but would enable higher levels of government auctioning (and more government revenue)
6. Achieving significant emission reductions in ETS sectors driven by a tight cap and high emission prices.

[21] The government has not yet announced whether it will attempt to carry over surplus AAUs from the first Kyoto commitment period (2008-2012) into the 2021-2030 period. It is not yet clear whether this would be allowed under the Paris Agreement.

FIGURE 4: NEW ZEALAND'S PROVISIONAL EMISSION BUDGET FOR 2021-2030



Source: Leining and Kerr (2017); adapted from Ministry for the Environment (2016b, 2017)

When deciding NZ ETS ambition, the decision whether to position biological emissions from agriculture outside or inside the NZ ETS is less important than the decision about how much the agriculture sector should be expected to contribute to domestic mitigation. The architecture for managing unit supply and prices proposed by Kerr et al. (2017) could accommodate either position for biological emissions.

4.2.2. REPLACE THE NZ ETS WITH A CARBON TAX

As an alternative to reforming the NZ ETS, it would be possible to dismantle the NZ ETS and replace it with a carbon tax. As discussed in section 2.3, depending on political support, a new carbon tax in New Zealand could adopt or change the existing NZ ETS settings regarding the scope of coverage; point of obligation; and requirements for measurement, monitoring, reporting and verification. Making the transition between instruments would require the following key steps:

1. *Setting the level of the emission price and the process for updating it over time.* The government would need to choose a carbon tax level that would help to deliver on New Zealand's targets efficiently and provide for a fair distribution of mitigation responsibility and costs between sectors facing the carbon tax, sectors exempt from the carbon tax, and general taxpayers. A credible and predictable long-term emission price signal would be needed to guide low-emission investment decisions in long-lived technology and infrastructure. The level of the carbon tax and the process for adjusting it would therefore need to have strong and enduring public and cross-party support.

2. *Creating a transitional process for managing banked NZUs and New Zealand Assigned Amount Units (NZ AAUs).*[22] Since 2008, NZ ETS participants have operated under policy settings that enabled them to bank NZUs and NZ AAUs under assurance of their long-term eligibility for surrender in the NZ ETS. They have made substantial investment decisions accordingly. When transitioning to a carbon tax, the government would need to identify a process for the disposition of banked NZUs and NZ AAUs. For example, the government could buy back banked units at a fixed price or accept banked units in lieu of carbon tax payments.
3. *Creating a transitional process for forests and industrial removal activities registered in the NZ ETS.* As noted in section 2.3, it would be possible to replace the current NZ ETS system of forestry liabilities and credits with a system that taxed deforestation of pre-1990 forest and reversal of credited removals in post-1989 forest, and provided a subsidy or credit for new planting on post-1989 land. A similar system could apply to industrial removals currently credited under the NZ ETS. In the NZ ETS, unit banking has been a useful feature for managing the emission and cost implications of harvesting cycles in post-1989 forests. The value of banking for this purpose could change under new forestry accounting rules that apply averaging, or alternatively could be achieved through new financing mechanisms operating beyond the emission pricing instrument.
4. *Assessing leakage potential under the carbon tax and providing appropriate safeguards.* Under the NZ ETS, the potential for emissions leakage by trade-exposed industrial producers is mitigated by providing output-based free allocation. A carbon tax set at levels in line with New Zealand's target could have comparable competitiveness implications for trade-exposed producers. Options for preventing leakage under a carbon tax include exemptions or rebates for some portion of the tax, or other forms of financial or other assistance.[23] Given past experience, the model of Negotiated Greenhouse Agreements (essentially a negotiated baseline-and-credit trading system in place of the tax) did not operate efficiently or transparently and should not be revived. Over time, as emission pricing or comparable regulations are adopted more widely by trade competitors, the rationale for free allocation or tax exemptions/rebates should decline.
5. *Adjusting the system for non-compliance and enforcement.* The ETS non-compliance provisions apply a unit make-good requirement as well as a financial penalty for failure to meet unit obligations. This is intended to safeguard environmental outcomes. Such provisions would require adjustment in the case of a carbon tax.
6. *Avoiding perverse outcomes during the transition.* Signals about changes to the level of emission prices and removal subsidies and the potential for government compensation for banked NZUs could distort market behaviour during the transition from the NZ ETS to the carbon tax.

The government's transitional process for managing banked NZUs and NZ AAUs would need to be legally, fiscally and politically acceptable. Legal advice would be needed regarding whether this constituted a government taking of private property for which fair compensation was required (Guerin

[22] In the past, the government issued NZ AAUs to participants in the Permanent Forest Sink Initiative, Projects to Reduce Emissions and Negotiated Greenhouse Agreements. These remain eligible for trading in the NZ ETS.
[23] One option that has been widely discussed is applying Border Tax Adjustments (BTAs). These would provide an emission price rebate at the point of export for New Zealand products, and an emission price levy at the point of import for goods manufactured overseas in jurisdictions without comparable policies to reduce emissions. BTAs would be very complex technically and politically.

2002). As of June 2017, the bank of NZUs and NZ AAUs totalled about 128 million units, of which about 82 million were held by individuals or organisations involved in forestry (Environmental Protection Authority 2017). At unit prices ranging from NZ$18 (the NZU price in mid-2017) to NZ$25 (the government's price ceiling), this could have a market value ranging from NZ$2.3 billion to NZ$3.2 billion. In 2016, the government projected that by 2021, the residual bank would have declined to 51 million units (Ministry for the Environment 2016b). At unit prices ranging from NZ$25-50 per tonne, this would range in value from NZ$1.3 billion to NZ$2.6 billion.

Under the NZ ETS, banked NZUs constitute a liability to the government under its international target. After 2020, the cost of this liability will depend on the cost to the government of purchasing international emission reductions and/or achieving further domestic emission reductions, both of which could rise over time. The timing of this liability will depend on how quickly the bank is depleted. Banking could be maintained at some market-driven level for the purpose of hedging risk and managing future harvesting or deforestation liabilities (Ministry for the Environment 2016b). Therefore, the cost to the government under its target from the surrender of banked units might occur gradually and rise over time. In contrast, under a buy-back scheme the government would presumably bear the cost in a lump sum up front. This could be offset over time by carbon tax revenue.

Decision makers currently face information gaps regarding New Zealand's technical and economic mitigation potential, sectors' responsiveness to emission pricing and the relative cost of purchasing international emission reductions. In this context, it would appear to be easier technically and politically for the government to set a quantity cap aligned with our targets and nominate price safeguards against unacceptable extremes than to determine a single efficient carbon price consistent with delivering on our targets and change it over time in response to domestic emission trends. The latter shifts considerable price risk for delivering mitigation to meet national targets from market participants to taxpayers.

4.2.3. COMPLEMENT THE NZ ETS WITH A CARBON TAX

A further policy option would be to introduce a carbon tax to operate alongside the NZ ETS. As elaborated in section 2.4, applying a carbon tax to ETS participants without adjusting the ETS cap would produce no further GHG mitigation gains beyond the cap. However, a carbon tax could redistribute mitigation effort within the cap or affect revenue generation. Three options for applying a complementary carbon tax would be:

1. Applying a carbon tax to all NZ ETS participants
2. Applying a carbon tax to a subset of NZ ETS participants
3. Applying a carbon tax to non-ETS sectors.

If a complementary carbon tax applied to all ETS participants, it would serve the same purpose as an ETS price floor: guaranteeing a minimum emission price regardless of price fluctuations in the trading market. The tax could be applied at the point of ETS auction or unit surrender for compliance. If applied at the point of surrender, it could potentially cover units purchased overseas or banked before the introduction of the tax. Applying a new carbon tax to previously banked units could damage public confidence in government rulemaking, as participants made those investments in response to previous policy. Setting the level of the carbon tax to try to correct for low prices for units purchased in the past or overseas could raise equity considerations for participants who purchased units with greater integrity or co-benefits at higher prices than others, or purchased units more recently in a tighter domestic market. Given the additional administrative burdens of creating a separate pricing instrument, an ETS price floor that is fully integrated within the ETS mechanism appears more practical and efficient than operating a supplemental carbon tax.

Alternatively, a complementary carbon tax could be applied only to a subset of NZ ETS participants. If their demand response was inelastic, the carbon tax would simply raise additional revenue without changing behaviour. If their demand response was elastic, the carbon tax could incentivise more emission reductions by the taxed participants, in which case others' emissions would increase under lower ETS prices under the cap. For example, a complementary carbon tax that discouraged burning coal in industrial boilers could simply increase other emissions in the NZ ETS – such as from transport – and lower the incentive for technology innovation elsewhere. This would not produce a least-cost emission outcome for the system as a whole, as some participants would face a higher marginal emission price than others. As well as distorting price signals, double taxation of a subset of participants would raise equity considerations (Sin, Kerr, and Hendy 2005). The literature on interactions between an ETS and other policies suggests that if a tax is combined with an ETS, the tax should be targeted at achieving other desirable policy outcomes (such as encouraging early adoption of new technologies so others can learn from these experiences) whose benefits outweigh the emission pricing efficiency losses (OECD 2011; Hood 2011, 2013; Goulder and Schein 2013).

Introducing a complementary carbon tax in non-ETS sectors could have equity implications if the price levels were significantly different from those in the NZ ETS. A low carbon tax in non-ETS sectors could shift more mitigation responsibility to NZ ETS sectors to achieve a given target, and vice versa. Applying a different emission price to sectors inside and outside the NZ ETS would reduce the cost-effectiveness of decarbonisation across the economy, but could be desirable for other administrative, economic or political reasons.

It would also be possible to apply comparable emission prices under both instruments. Essentially this practice has been applied in the case of HFCs and PFCs in imported goods, which were removed from the scope of the NZ ETS and subjected to a levy intended to approximate the NZ ETS price. This was done to reduce administrative requirements and transaction costs for the relatively large number of relatively small points of obligation (Leining, Allan, and Kerr 2017).

It would be possible to apply a distinct carbon tax to some or all biological emissions from agriculture as an alternative to entry into the NZ ETS. If the goal was to moderate the agriculture sector's exposure to an emission price, this could also be achieved under the NZ ETS through free allocation, a progressive unit obligation, or a change to the metric applied to biological emissions; a separate carbon tax would not be required for this purpose. The same challenges regarding selection of the point of obligation and implementation of emissions monitoring, reporting and verification would apply regardless of whether biological emissions were under a carbon tax or the NZ ETS. The same arguments regarding how the agriculture sector would respond to an emission price would apply to both instruments.

Several European Union (EU) Member States have maintained or introduced carbon (or energy) taxes alongside the European Union Emissions Trading System (EU ETS). Many of these have been targeted at the transport sector, which is not covered by the EU ETS. In some cases, Member States have exempted EU ETS participants from other emissions-related taxes (see the Annex). When supplemental carbon taxes have been applied to EU ETS participants, there has been no global emission benefit beyond the EU ETS cap (OECD 2011). However, those Member States have decided to capture domestic benefits from the supplemental carbon tax in terms of accelerating local technology innovation or fuel switching and generating revenue which can be used for strategic purposes.

For example, the UK has implemented a “Carbon Price Floor” by adding a “top up” fee to the emission price paid by electricity-sector participants in the EU ETS. The goal is to strengthen price signals for renewable energy despite low emission prices in the EU ETS. This has not produced any global emission benefit beyond the EU ETS cap, but has had a significant impact on reducing coal-fired generation in the UK (Ares and Delebarre 2016).

In the case of the EU, a unique and important consideration is that individual Member States cannot control the level of the cap in the EU ETS, and the system has struggled with over-allocation and low emission prices since inception. Traditionally, taxation in the EU has been the domain of individual Member States. Some Member States already had carbon or energy taxes in place and chose to retain them after the EU ETS was introduced for continuity of price incentives and revenue. Member States have been unable to agree on setting a uniform price floor across the EU ETS, despite pressure from some.

An ETS price floor can deliver the same benefits as a complementary carbon tax within a single integrated instrument that helps the market to discover an efficient marginal emission price for achieving a given target. If the rationale for introducing a complementary carbon tax in NZ ETS sectors is accelerating specific types of higher-cost mitigation or overcoming inelastic price responses, then a more effective approach could be to introduce command-and-control regulations to achieve desired outcomes and adjust the NZ ETS cap downward accordingly to maintain an effective emission price incentive across the rest of the economy.

4.3. ASSESSMENT OF OPTIONS AGAINST EMISSION PRICING POLICY OBJECTIVES

The table below presents a brief evaluation of the policy options discussed above against the emission pricing policy objectives identified in section 4.1.

TABLE 2: ASSESSMENT OF POLICY OPTIONS AGAINST OBJECTIVES

Emission pricing policy objective	Reformed NZ ETS	Broad carbon tax in place of NZ ETS	NZ ETS plus carbon tax
Maintain government sovereignty over domestic emissions and emission prices	Achieved with quantity limits on use of overseas units by ETS participants.	Achieved unless the carbon tax is indexed to international prices in some way (which was considered under the 2002 carbon tax proposal in New Zealand).	Same conditions as for NZ ETS and broad carbon tax.
Raise domestic emission price ambition over time in line with New Zealand's international targets and objectives for domestic decarbonisation	Determined by the combination of the cap on units auctioned and freely allocated, price management mechanisms, and limits on use of overseas units by ETS participants.	Determined by the level of the carbon tax and price responsiveness by covered sectors.	Same conditions as for NZ ETS and broad carbon tax.
Improve policy and price predictability to support efficient low-emission investment	Enabled by predicable processes for coordinating decisions on unit supply, price management and linking. Strengthened by independent advice and cross-party support.	Enabled by predicable processes for coordinating decisions on setting and updating the carbon tax. Strengthened by independent advice and cross-party support.	Combining emission pricing instruments can reduce policy and price predictability and the efficiency of mitigation responses with no further mitigation gains beyond the ETS cap.
Distribute emission reduction responsibilities, costs and risks fairly and efficiently across ETS sectors, non-ETS sectors and government/taxpayers	Managed through: (1) setting the cap within a broader emission budget covering ETS and non-ETS sectors, and with regard to the price of international emission reductions; (2) free allocation; (3) recycling of auction revenue to the economy or society; and (4) transitional assistance to vulnerable entities.	Managed through: (1) setting the price within a broader emission budget covering ETS and non-ETS sectors, and with regard to the price of international emission reductions; (2) exemptions or rebates; (3) recycling of tax revenue to the economy or society; and (4) transitional assistance to vulnerable entities.	Same conditions as for NZ ETS and broad carbon tax. Applying different emission prices to different subsets of ETS participants, or between ETS and non-ETS sectors, reduces the cost-efficiency of mitigation across the economy and can raise equity considerations.
Mitigate potential emissions leakage to other jurisdictions	Managed through output-based free allocation to trade-exposed producers.	Managed through exemptions or rebates to trade-exposed producers.	Same conditions as for NZ ETS and broad carbon tax.

Emission pricing policy objective	Reformed NZ ETS	Broad carbon tax in place of NZ ETS	NZ ETS plus carbon tax
Maintain environmental integrity, transparency, compliance and enforcement	Can be managed through strong government systems and capacity building for participants.	Can be managed through strong government systems and capacity building for participants.	Same conditions as for NZ ETS and broad carbon tax.
Manage uncertainties and risks (environmental, economic, fiscal and social)	Provides greater certainty on emission outcomes and less certainty on price outcomes; however, price certainty can be improved using a hybrid approach with a price band. The cap can be adjusted over time.	Provides greater certainty on price outcomes and less certainty on emission outcomes; greater target performance risk is transferred to government. The price level can be adjusted over time. Transitioning between instruments could increase policy and price uncertainty.	Creates additional uncertainties and risks from interactions between pricing instruments.
Manage interactions with other policies	Policies that remove non-price barriers to mitigation can make an ETS more effective. Policies that drive higher-cost emission reductions in ETS sectors can reduce cost effectiveness without further mitigation gains beyond the cap.	Policies that remove non-price barriers to mitigation can make a carbon tax more effective. Policies that drive higher-cost emission reductions in taxed sectors can create additive mitigation gains.	Creates additional uncertainties and risks from interactions between multiple pricing instruments and other policies.
Raise and manage revenue strategically	Revenue is generated by auctioning units. As free allocation is phased out, auction revenue can increase. Revenue can be returned to the economy or society through many channels.	Revenue is generated by the carbon tax. As exemptions or rebates are phased out, carbon tax revenue can increase. Revenue can be returned to the economy or society through many channels.	Same conditions as for NZ ETS and broad carbon tax.
Achieve broad and enduring public and cross-party acceptance	An ETS can be harder for the public to understand. Acceptance will depend on past experience and future expectations for operation.	A carbon tax can be easier for the public to understand. Acceptance will depend on past experience and future expectations for operation.	Double taxation is likely to be unpopular among participants in the NZ ETS, and misunderstood by the public.

5. CONCLUSION

If well designed and based on good information and sound assumptions, an ETS and a carbon tax can deliver comparable outcomes. Under uncertainty, their outcomes can differ significantly unless the instruments include hybrid features, such as price-based adjustment of ETS supply, or are updated over time. For both instruments, the key determinants of long-term success are effective design, supply/price predictability, government policy commitment, and social and political acceptance. Both instruments would need to be positioned strategically within a broader and coordinated climate change policy portfolio to help deliver on New Zealand’s targets. Experience suggests a carbon tax is much easier to understand than an ETS – but no less vulnerable to the winds of political change. When a jurisdiction is starting from a blank slate and has sufficient capacity to take either approach, then either a carbon tax or ETS will do if it is done well and with enduring commitment.

When constituents are disgruntled about the deficiencies of the current system – whether tax or trading – it can be tempting to assume an alternative emission pricing instrument would correct them. Whether those deficiencies actually can be – and will be – corrected by changing instruments mid-course instead of reforming the current instrument deserves careful consideration. When particular design features are the product of the political economy, those same forces will come to bear on both instruments. As discussed in section 2, common perceptions that carbon taxes automatically offer more price ambition, more investment certainty, more revenue, more effective revenue recycling, more simplicity, more transparency, and fewer “handouts to big business” do not hold true in theory or in international experience. To borrow the adage, the price may not be greener in the other instrument. If changing instruments mid-course delays implementation of a more ambitious price signal by starting a new complex legislative process, re-opens contentious political debates, disrupts market confidence in government rulemaking, and devalues assets created and investments made under the previous instrument, then the environmental, economic and fiscal costs could outweigh hoped-for gains.

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ANNEX: OVERVIEW OF EMISSION PRICING INSTRUMENTS

Name of the initiative	Type of the initiative	Status of the initiative	Year of implementation	Description of the initiative	Jurisdictions covered	Coverage of jurisdiction's GHG emissions	Sectors and/or fuels covered	Overlap with other carbon pricing initiatives	Relation to other carbon pricing initiatives
Alberta SGER	ETS	Implemented	2007	The Alberta Specified Gas Emitters Regulation (SGER) is a baseline-and-credit system which requires large emitters to reduce their emissions intensity (i.e. emissions per unit of production), aiming to regulate GHG emissions from large industrial emitters.	Alberta	45%	The Alberta SGER applies to GHG emissions from the industry and power sectors except for industrial process emissions.	Not applicable	Operators under the Alberta SGER are exempt from the Alberta carbon tax.
Alberta carbon tax	Carbon tax	Implemented	2017	The Alberta carbon tax (official name: Carbon Levy) is contained in the Climate Leadership Implementation Act which aims to reduce GHG emissions. The tax serves as a complementary policy measure to the Alberta SGER.	Alberta	45%	The Alberta carbon tax applies to GHG emissions from all sectors with some exemptions for the industry and agriculture sectors. The tax covers all fossil fuels.	Not applicable	Operators covered by the Alberta SGER are exempt from the carbon tax.
Australia ERF (safeguard mechanism)	ETS	Implemented	2016	The safeguard mechanism to the Emission Reduction Fund (ERF) came into effect on July 1, 2016, launching a baseline-and-offset system. It intends to ensure that emission reductions purchased by the Australian Government through the ERF are not offset by significant increases in emissions above business-as-usual levels elsewhere in the economy.	Australia	50%	The safeguard mechanism applies to GHG emissions from the industry and power sectors and includes industrial process emissions.	Not applicable	Not applicable

Name of the initiative	Type of the initiative	Status of the initiative	Year of implementation	Description of the initiative	Jurisdictions covered	Coverage of jurisdiction's GHG emissions	Sectors and/or fuels covered	Overlap with other carbon pricing initiatives	Relation to other carbon pricing initiatives
British Columbia GGIRCA	ETS	Implemented	2016	The British Columbia Greenhouse Gas Industrial Reporting and Control Act (GGIRCA) enables a price to be put on emissions of industrial facilities or sectors exceeding a specific limit, in addition to the provinces existing revenue neutral carbon tax. This established a baseline-and-credit system that will covers liquefied natural gas (LNG) facilities currently under construction, once they become operational.	British Columbia	0%	The GGIRCA applies to GHG emissions from liquefied natural gas (LNG) facilities currently under construction, once they become operational.	100% Estimated based on overlap with: BC carbon tax	Operators under the GGIRCA are also covered under the BC carbon tax. The GGIRCA includes the option for operators to use emission units from other jurisdictions to meet their compliance obligations, but these rules are yet to be defined.
British Columbia carbon tax	Carbon tax	Implemented	2008	The British Columbia carbon tax (official name: B.C.'s Revenue Neutral Carbon Tax) aims to encourage people and businesses to innovate and find the most cost-efficient methods of reducing emissions to pay less in carbon tax. Revenue neutral means that the carbon tax revenue is recycled back into the economy through various income tax reductions and tax credits.	British Columbia	70%	The BC carbon tax applies to GHG emissions from all sectors with some exemptions for the industry, aviation, transport and agriculture sectors. The tax covers all fossil fuels and tires combusted for heat or energy.	No overlap yet as facilities covered under the BC GGIRC are not yet operational	Not applicable
Beijing pilot ETS	ETS	Implemented	2013	The Beijing pilot ETS is a cap-and-trade system that aims to control GHG emissions and coordinate measures against air pollution. It is also a key measure for the city of Beijing to meet its carbon intensity reduction target.	Beijing	45%	The Beijing pilot ETS applies to CO_2 emissions from the industry, power, transport and buildings sectors.	Not applicable	The Beijing pilot ETS is to be merged into the national ETS under unified rules and a detailed transition plan is under development.

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Brazil (Undecided)	Undecided	Under consideration	TBC	Brazil enacted in December 2009 the National Climate Change Policy, which aims for the development of a Brazilian emissions reduction market. Since then, progress on the plans for a carbon pricing initiative have been limited. However, some companies have shown interest in gaining practical experience in an ETS to form their own perspective. This led to the launch of the Emissions Trading Scheme of the Businesses for Climate Platform (SCE EPC) in 2014. The SCE EPC is a simulated ETS covering 60 $MtCO_2e$ in 2016. Allowances can be traded through the exchange platform BVTrade.					
California CaT	ETS	Implemented	2012	The California Cap-and-Trade Program is a cap-and-trade system that aims to help put California on the path to meet its goal of reducing GHG emissions to 1990 levels by 2020 and ultimately achieving an 80 percent reduction from 1990 levels by 2050.	California	85%	The California CaT applies to CO_2, CH_4 and N_2O emissions from the industry, power, transport and buildings sectors and includes industrial process emissions.	Not applicable	The California CaT linked with the Quebec CaT in January 2014 under the Western Climate Initiative WCI. The amendments proposed in August 2016 include modalities to take into account a linkage with the Ontario CaT in 2018. California is also working on emissions trading with British Columbia and Manitoba under the WCI.

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Canada (Undecided)	Undecided	Under consideration	TBC	On October 3, 2016, the Canadian federal government put forward a national framework to put a price on GHG emissions. The framework requires all jurisdictions to implement a carbon price through a tax or an ETS by 2018, covering at least GHG emissions from all fossil fuel combustion. Jurisdictions can implement either a carbon tax or an ETS.					
Chile (ETS)	ETS	Under consideration	TBC	The implementation of the Chile carbon tax and a monitoring, reporting and verification system is designed to be ETS compatible to facilitate the possible implementation of an ETS in the future.					
Chile carbon tax	Carbon tax	Implemented	2017	The Chile carbon tax is a part of the tax on air emissions from contaminating compounds (impuesto destinado a gravar las emisiones al aire de compuestos contaminantes) and aims to reduce the negative impacts of fossil fuel use for the environment and public health. The tax is part of wider tax reforms to increase taxes for big businesses and lowering them for individuals.	Chile	42%	The Chile carbon tax applies to CO_2 emissions from mainly the power and industry sectors, as it applies to all establishments with stationary sources of a thermal input capacity greater than 50 megawatts. The tax covers all fossil fuels.	Not applicable	Not applicable

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China (ETS)	ETS	Under consideration	TBC	On September 25, 2015, the Chinese President announced that the Chinese national ETS will commence in 2017. The national ETS will cover power generation, petrochemicals, chemicals, building materials, steel, non-ferrous metals, paper and aviation. The National Development and Reform Commission is responsible for developing the rules of the national ETS while the local Development and Reform Commissions are responsible for the implementation and management in their jurisdiction. If the Chinese national ETS is implemented in 2017 as announced, the Chinese national ETS would become the largest carbon pricing initiative in the world.					
Chongqing pilot ETS	ETS	Implemented	2014	The Chongqing pilot ETS was the last of the original seven Chinese pilot ETS to start and has experienced limited trading on its carbon market. The cap-and-trade system aims to strengthen the management and control on GHG emissions while promoting a low-carbon society and accelerating the transformation of the economy.	Chongqing	40%	The Chongqing pilot ETS applies to GHG emissions from the industry and power sectors.	Not applicable	The Chongqing pilot ETS is to be merged into the national ETS under unified rules and a detailed transition plan is under development.

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Colombia (ETS)	ETS	Under consideration	TBC	Colombia is considering an ETS and has been part of dialogues in 2016 in the context of the Pacific Alliance to explore regional carbon pricing. These dialogues focus on the growing momentum to use carbon pricing policies to achieve regional green growth, the opportunities for improved regional collaboration and future carbon pricing pathways for the region.					
Colombia carbon tax	Carbon tax	Implemented	2017	The Colombia carbon tax (official name: Impuesto nacional al carbono) was adopted as part of a structural tax reform.	Colombia	30%	The Colombia carbon tax applies to GHG emissions from all sectors with some minor exemptions. The tax covers all liquid and gaseous fossil fuels.	Not applicable	Not applicable
Denmark carbon tax	Carbon tax	Implemented	1992	The Denmark carbon tax (official name: CO_2-afgift) was introduced to increase the profile of climate change and provide an economic incentive to consume less energy from carbon-intensive sources. It was introduced gradually as part of a larger environmental tax package, which includes energy taxes and a sulfur tax, as well as subsidies for green investments.	Denmark	40%	The Denmark carbon tax applies to CO_2 emissions from mainly the buildings and transport sectors as there are (partial) exemptions for other sectors. The tax covers all fossil fuels.	Overlap with the EU ETS not available due to a lack of data	Almost all operators covered by the EU ETS are exempt from the carbon tax.
EU ETS	ETS	Implemented	2005	The European Union Emissions Trading System (EU ETS), currently in its third phase which operates from 2013 to 2020, is the	EU, Norway, Iceland, Liechtenstein	45%	The EU ETS applies to CO_2 emissions from the industry, power and aviation sectors and	8% Estimated based on overlap with: Finland carbon tax, Ireland carbon	Operators covered by the EU ETS are exempt from most carbon taxes (See Overlap with other

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				European Union's flagship climate policy initiative. The EU ETS is a cap-and-trade system which started in 2005 and is the world's longest-running ETS.			includes industrial process emissions. It also covers N2O emissions from the certain chemical sectors and PFC emissions from the aluminium sector.	tax, UK carbon price floor, Norway carbon tax, N/A The minor overlap with the following carbon pricing initiatives could not be taken into account due to a lack of available data: Denmark carbon tax, Estonia carbon tax, Iceland carbon tax, Latvia carbon tax, Slovenia carbon tax, Sweden carbon tax	carbon pricing initiatives). Following negotiations which started in 2011, Switzerland and the EU reached an agreement on January 25, 2016 to link their ETSs with the timeline to be defined. The European Commission also announced cooperative initiatives with China and the Republic of Korea in June and July 2016, respectively. The cooperation with China focuses on addressing the challenges of implementing an ETS and establishes a dialogue to discuss developments in emissions trading. Similarly, the European Commission will provide technical assistance on the implementation of emissions trading to the Republic of Korea.
Estonia carbon tax	Carbon tax	Implemented	2000	The Estonia carbon tax is part of the Environmental Charges Act (Keskkonnatasude seadus), which aims to limit environmental pollution.	Estonia	3%	The Estonia carbon tax applies to CO_2 emissions from industry and power sectors. The tax covers all fossil fuels used to	Overlap with the EU ETS not available due to a lack of data	Operators covered by the EU ETS are also covered by the carbon tax.

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							generate thermal energy.		
Finland carbon tax	Carbon tax	Implemented	1990	Finland introduced their carbon tax (official name: Hiilidioksidivero) in 1990, making it the first country to introduce a carbon tax. The carbon tax is a component of the energy tax (official name: energiaverotusta). The energy tax further consists of a variable component based on the energy content of the fuel and a fixed component to finance maintaining security of supply.	Finland	36%	The Finland carbon tax applies to CO_2 emissions from mainly the industry, transport and buildings sectors with some exemptions for industry. The tax covers all fossil fuels except for peat.	37% Estimated based on overlap with: EU ETS	Operators covered by the EU ETS are also covered by the carbon tax.
France carbon tax	Carbon tax	Implemented	2014	The French carbon tax is a part of the domestic tariffs on consumption of the energy products (taxes intrieures sur la consommation des produits nergtiques). The tax was introduced to include the impact of products on climate change and serves as a complementary policy measure to the EU ETS.	France	35%	The French carbon tax applies CO_2 emissions from mainly the industry, buildings and transport sectors with some exemptions for these and other sectors. The tax covers all fossil fuels.	Not applicable	Operators covered by the EU ETS are exempt from the carbon tax.
Fujian pilot ETS	ETS	Implemented	2016	The Fujian pilot ETS is the eighth Chinese ETS pilot. The cap-and-trade system intends to prepare companies for the start of the national ETS. It also aims to encourage investments in and development of carbon sequestration projects.	Fujian	60%	The Fujian pilot ETS applies to CO_2 emissions from the industry, power and aviation sectors.	Not applicable	The Fujian pilot ETS is to be merged into the national ETS under unified rules and a detailed transition plan is under development.

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Guangdong pilot ETS	ETS	Implemented	2013	The Guangdong pilot ETS is the largest ETS among the Chinese ETS pilots. The cap-and-trade system is a key instrument for the province to transform and upgrade its economy, increase welfare and raise awareness of GHG emission control among society and businesses.	Guangdong	60%	The Guangdong pilot ETS applies to CO_2 emissions from the industry, power and aviation sectors.	Not applicable	The Guangdong pilot ETS is to be merged into the national ETS under unified rules and a detailed transition plan is under development.
Hubei pilot ETS	ETS	Implemented	2014	The Hubei pilot ETS has the most active market among the Chinese ETS pilots. The cap-and-trade system is a key instrument in achieving the province's GHG emission reduction target by turning carbon emissions into a resource and giving it a value by establishing resource scarcity through the a cap on emissions.	Hubei	35%	The Hubei pilot ETS applies to CO_2 emissions from the industry and power sectors.	N/A	The Hubei pilot ETS is to be merged into the national ETS under unified rules and a detailed transition plan is under development.
Iceland carbon tax	Carbon tax	Implemented	2010	The Iceland carbon tax (official name: Kolefnisgjald kolefni af jarefnauppruna) is part of the Environmental and Resource tax. The tax was introduced as part of the government's tax reform on vehicles and fuels to encourage the use of environment-friendly vehicles, save energy, reduce GHG emissions and increase the use of domestic energy sources. The tax serves as a complementary policy measure to the EU ETS.	Iceland	55%	The Iceland carbon tax applies to CO_2 emissions from all sectors with some exemptions for the industry, power and aviation sectors. The tax covers liquid and gaseous fossil fuels.	Not applicable	Operators covered by the EU ETS are exempt from the carbon tax.

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Ireland carbon tax	Carbon tax	Implemented	2010	The Ireland carbon tax (officially under three names: Natural Gas Carbon Tax, Mineral Oil Tax: Carbon Charge and Solid Fuel Carbon Tax) aims to reduce GHG emissions while using the revenues to boost energy efficiency, to support rural transport, to alleviate fuel poverty and to maintain or reduce payroll taxes. The tax serves as a complementary policy measure to the EU ETS.	Ireland	49%	The Ireland carbon tax applies to CO_2 emissions from all sectors with some exemptions for the power, industry, transport and aviation sectors. The tax covers all fossil fuels.	40%Estimated based on overlap with: EU ETS	Operators covered by the EU ETS are partly exempt from the tax.
Japan (ETS)	ETS	Under consideration	TBC	An ETS has been under consideration in Japan since 2008. The Ministry of Environment continues (2017) to hold stakeholder discussions and explore options for a national ETS.					
Japan carbon tax	Carbon tax	Implemented	2012	The Japan carbon tax (official name: Tax for Climate Change Mitigation) aims to put an economy-wide and fair burden for the use of all fossil fuels based on their CO_2 content to realize a low-carbon society and strengthen climate change mitigation.	Japan	68%	The Japan carbon tax applies to CO_2 emissions from all sectors with some exemptions for the industry, power, agriculture and transport sectors. The tax covers all fossil fuels.	2%Estimated based on overlap with: Tokyo CaT, Saitama ETS	The Japan carbon tax does not consider the interaction with other carbon pricing initiatives.
Kazakhstan ETS	ETS	Implemented	2013	The Kazakhstan Emissions Trading Scheme started with a pilot phase in 2013 as a cap-and-trade system covering CO_2 emissions of large emitters. Full enforcement of regulations and trading in the	Kazakhstan	50%	The Kazakhstan applies to CO_2 emissions from the industry and power sectors.	Not applicable	Not applicable

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				Kazakhstan ETS started in 2014.					
Korea ETS	ETS	Implemented	2015	The Republic of Korea launched its national ETS (Korea ETS) in 2015, the first national cap-and-trade system in operation in East Asia. The Korea ETS plays an essential role in meeting Korea's 2030 NDC targets, aiming to reduce GHG emissions in a cost-effective manner, transform the Korean industry to a low-carbon highly energy efficient industry and create new growth through green technology.	Korea, Republic of	68%	The Korea ETS applies to GHG emissions from the industry, power, buildings, aviation and waste sectors.	Not applicable	The Republic of Korea is cooperating with various international counterparts on carbon pricing. In December 2015, the carbon exchanges of Korea and Beijing signed an MoU to research cooperation between their respective carbon markets. Also, the Republic of Korea and China held the Joint Committee on Climate Change Cooperation and Roundtable on ETS in June, 2016 where views on climate policy and carbon markets were exchanged.
Latvia carbon tax	Carbon tax	Implemented	1995	The Latvia carbon tax (official name: Nodokli par oglekla dioksida) is part of the Natural Resources Tax Law (Dabas resursu nodokla likums), which aims to limit environmental pollution such as water and air pollution.	Latvia	15%	The Latvia carbon tax applies to CO_2 emissions from the industry and power sectors not covered under the EU ETS. The tax covers all fossil fuels except for peat.	Overlap with the EU ETS not available due to a lack of data	Operators covered by the EU ETS are exempt from the carbon tax.

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Liechtenstein carbon tax	Carbon tax	Implemented	2008	The Liechtenstein carbon tax was implemented as a result of a bilateral treaty that requires Liechtenstein to transpose Swiss federal legislation on environmental levies into national law.	Liechtenstein	26%	The Liechtenstein carbon tax applies to CO_2 emissions from mainly the industry, power, buildings and transport sectors. The tax covers all fossil fuels.	Not applicable	Operators covered by the EU ETS are exempt from the carbon tax.
Manitoba (Undecided)	Undecided	Under consideration	TBC	Manitoba is planning to introduce a "Made in Manitoba" carbon pricing initiative and climate change plan to address both its unique environmental circumstances and meet its economic realities. Manitoba is currently (2017) considering carbon pricing options.					
Mexico (Undecided)	Undecided	Under consideration	TBC	Mexico launched an ETS simulation in November 2016 to prepare Mexican companies for its ETS, which is scheduled to start in 2018. About 60 companies from the transport, power and industry sectors are participating in the ETS simulation on a voluntary basis. The simulation will not involve any real transactions. The simulation is scheduled to end in December 2017, before the launch of the pilot ETS.					

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Mexico carbon tax	Carbon tax	Implemented	2014	The Mexican carbon tax is an excise tax under the special tax on production and services (Ley del impuesto especial sobre produccin y servicios). It is not a tax on the full carbon content of fuels, but on the additional CO2 emission content compared to natural gas.	Mexico	46%	The Mexican carbon tax applies to CO_2 emissions from all sectors. The tax covers all fossil fuels except natural gas.	Not applicable	Not applicable
New Zealand ETS	ETS	Implemented	2008	The New Zealand Emissions Trading Scheme (NZ ETS) is New Zealand's principle polcy response to climate change. It aims to support efforts to reduce GHG emissions while maintaining economic productivity.	New Zealand	51%	The NZ ETS applies to GHG emissions from the industry, power, waste, transport and forestry sectors and includes industrial process emissions.	Not applicable	New Zealand and China signed a bilateral climate change action plan to cooperate on carbon markets. The plan includes identifying opportunities for collaboration with other countries in the Asia-Pacific region to discuss potential linking. Also, New Zealand started discussions with Korea on developing carbon markets in the Asia-Pacific region.
Newfoundland and Labrador (Undecided)	Undecided	Under consideration	TBC	On June 7, 2016, Newfoundland and Labrador announced plans for a carbon pricing initiative that applies to onshore industrial facilities with annual GHG emissions exceeding 25 $ktCO_2e$, covering 19% of the provinces GHG emissions. Prior to the launch of the initiative, a two year emissions monitoring period will be implemented, which					

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				will help establish emission reduction targets.					
Norway carbon tax	Carbon tax	Implemented	1991	The Norway carbon tax (official name: CO_2 avgift) aims to achieve cost-effective GHG emissions. The carbon tax is split into an excise tax on mineral products and a separate law for petroleum activities on the continental shelf.	Norway	60%	The Norway carbon tax applies to GHG emissions from all sectors with some exemptions for certain sectors. The tax covers liquid and gaseous fossil fuels.	30% Estimated based on overlap with: EU ETS	Operators covered by the EU ETS are exempt from the carbon tax, except for offshore oil production activities.
Ontario CaT	ETS	Implemented	2017	The Ontario cap and trade program is designed to help fight climate change, and reward businesses that reduce their greenhouse gas emissions. The cap-and-trade system is mandatory for large emitters and medium-sized emitters can choose to opt in.	Ontario	82%	The Ontario CaT applies to GHG emissions from the industry, power, transport, and buildings sectors, and include industrial process emissions.	Not applicable	Ontario's scheme has been developed using the Western Climate Initiative model in order to facilitate future linkage to the California-Quebec ETSs. Ontario is working with Quebec and California with the intent to link its ETS in 2018.
Oregon (ETS)	ETS	Under consideration	TBC	Oregon continues to study carbon pricing options, including a cap-and-trade program that could be linked to the California and Quebec ETS. In addition, lawmakers launched several new bills and draft proposals in 2017 that seek the introduction of a carbon pricing initiative.					

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Poland carbon tax	Carbon tax	Implemented	1990	The Poland carbon tax is part of the Environmental Protection Act (Prawo ochrony srodowiska), which taxes different kinds of environmental emissions such as CO_2 emissions, dust, sewage and waste.	Poland	4%	The Poland carbon tax applies to GHG emissions from all sectors with some exemptions for certain entities. The tax covers all fossil fuels and other fuels leading to GHG emissions.	Not applicable	Operators covered by the EU ETS are exempt from the carbon tax.
Portugal carbon tax	Carbon tax	Implemented	2015	The Portugal carbon tax is an excise tax under the special taxes on consumption (Cdigo dos Impostos Especiais de Consumo). The tax was introduced as part of wider package of green tax reforms and serves as a complementary policy measure to the EU ETS.	Portugal	29%	The Portugal carbon tax applies to CO_2 emissions from mainly the industry, buildings and transport sectors with some exemptions for these and other sectors. The tax covers all fossil fuels.	Not applicable	Operators covered by the EU ETS are exempt from the tax. The tax rate under the Carbon Price Floor depends on the EU ETS price (See Future price developments).
Quebec CaT	ETS	Implemented	2013	The Quebec Cap-and-Trade System aims to reduce GHG emissions in the highest emitting sectors by promoting energy efficiency as well as the use of energy from renewable sources. The cap-and-trade system intends to stimulate innovation by fostering the emergence of new low carbon drivers for economic development.	Quebec	85%	The Quebec CaT applies to GHG emissions from the industry, power, transport and buildings sectors and includes industrial process emissions.	Not applicable	The Quebec CaT linked with the California CaT in January 2014 under the Western Climate Initiative (WCI).Manitoba, Ontario, and Quebec signed a memorandum of understanding (MoU) that stated their intention to link their ETSs under the WCI.

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RGGI	ETS	Implemented	2009	The Regional Greenhouse Gas Initiative (RGGI) is a cap-and-trade system covering CO_2 emissions from power plants in the Northeast and Mid-Atlantic US states. It is the first mandatory ETS in the United States and is a cooperative effort among the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont to reduce GHG emissions.	RGGI	21%	RGGI covers CO_2 emissions only from the power sector.	Not applicable	Not applicable
Rio de Janeiro (ETS)	ETS	Under consideration	TBC	In 2011 Rio de Janeiro announced its intention to launch a state-wide ETS. However, progress on the subnational ETS as stalled due to opposition from industry.					
Saitama ETS	ETS	Implemented	2011	The Saitama target setting type ETS is a baseline-and-credit system that sets mandatory emission reduction targets for large emitters.	Saitama	16%	The Saitama ETS applies to energy-use related CO_2 emissions from the industry, power and buildings sectors.	100%Estimated based on overlap with: Japan carbon tax	The Saitama ETS is linked to the Tokyo CaT and operators can use credits from the Tokyo CaT to meet their compliance.
Sao Paolo (ETS)	ETS	Under consideration	TBC	In June 2012 So Paolo announced plans to launch an ETS. However, no progress has been made since then.					

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Shanghai pilot ETS	ETS	Implemented	2013	The Shanghai pilot ETS is a cap-and-trade system that aims to promote the implementation of carbon emission control responsibilities and support the achievement of Shanghai's emission reduction targets.	Shanghai	57%	The Shanghai pilot ETS applies to CO_2 emissions from the industry, power, buildings and transport sectors.	Not applicable	The Shanghai pilot ETS is to be merged into the national ETS under unified rules and a detailed transition plan is under development.
Shenzhen pilot ETS	ETS	Implemented	2013	The Shenzhen pilot ETS is the first Chinese pilot ETS, launching an intensity-based cap-and-trade system in the city of Shenzhen. The Shenzhen pilot ETS is seen as a means for stable economic growth and comprehensive sustainable development.	Shenzhen	40%	The Shenzhen pilot ETS applies to CO_2 emissions from the industry, power, buildings and transport sectors.	Not applicable	The Shenzhen pilot ETS is to be merged into the national ETS under unified rules and a detailed transition plan is under development.
Singapore (Carbon tax)	Carbon tax	Under consideration	TBC	The Singaporean government intends to introduce a carbon tax in 2019. A carbon tax of between S$10-20/t$CO_2$e (US$7-14/tCO_2e) will apply to direct emitters and the revenue raised will help to fund industrial emission reduction measures.					
Slovenia carbon tax	Carbon tax	Implemented	1996	The Slovenia carbon tax (official name: Okoljska dajatev za onesnaevanje zraka z emisijo CO_2 za zgorevanje goriva) is part of a number of environmental taxes, which aim to limit environmental pollution.	Slovenia	24%	The Slovenia carbon tax applies to CO_2 emissions from mainly the buildings and transport sector as there are exemptions for other sectors. The tax covers all fossil fuels.	Overlap with the EU ETS not available due to a lack of data	Almost all operators covered by the EU ETS are exempt from the carbon tax.

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South Africa carbon tax	Carbon tax	Scheduled	2017	The South Africa carbon tax aims to price carbon by obliging the polluter to internalise the external costs of emitting carbon, and contribute towards addressing the harm caused by such pollution.	South Africa	80%	In the draft bill, the South Africa carbon tax applies to GHG emissions from the industry, power, buildings and transport sectors irrespective of the fossil fuel used, with partial exemptions for all these sectors.	Not applicable	Not applicable
Sweden carbon tax	Carbon tax	Implemented	1991	The Sweden carbon tax (official name: Koldioxidskatt) is part of the energy tax (official name: skatt p energi). The tax placed on carbon-intensive fuels aims to actively reduce dependency of fossil fuels.	Sweden	40%	The Swedish carbon tax applies to CO_2 emissions from mainly the buildings sector as there are many (partial) exemptions for other sectors).The tax covers all fossil fuels.	Overlap with the EU ETS not available due to a lack of data	Almost all operators covered by the EU ETS are exempt from the carbon tax.
Switzerland ETS	ETS	Implemented	2008	The Switzerland Emissions Trading System is a mandatory cap-and-trade system. The ETS began with a first phase over 2008 to 2012, during which companies could opt in on a voluntary basis instead of facing the Switzerland carbon tax. In its current phase from 2013 to 2020, the ETS is mandatory for large energy-intensive industries and medium-sized industries can choose to opt in.	Switzerland	11%	The Switzerland ETS applies to GHG emissions from the industry and power sectors and includes industrial process emissions.	Not applicable	Following negotiations which started in 2011, Switzerland and the EU reached an agreement on January 25, 2016 to link their ETSs with the timeline to be defined. Participants in the ETS are exempt from the carbon tax.

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Switzerland carbon tax	Carbon tax	Implemented	2008	The Switzerland carbon tax (official name: CO_2 levy) is a central instrument in the Swiss climate policies under the CO_2 Act to contribute to limiting the global rise in temperature to less than 2 degrees Celsius. The tax serves as a complementary policy measure to the Switzerland ETS.	Switzerland	33%	The Switzerland carbon tax applies to CO_2 emissions from mainly the industry, power, buildings and transport sectors. The tax covers all fossil fuels.	Not applicable	Operators covered by the Switzerland ETS are exempt from the carbon tax.
Taiwan (ETS)	ETS	Under consideration	TBC	On June 15, 2015, Taiwan adopted the Greenhouse Gas Reduction and Management Act. This law sets an emission reduction target of 50 percent below 2005 levels by 2050. In February 2017, plans were published to meet this target through the implementation of an ETS, among other policy measures. and indicates that one of the major means to achieve this target will be an ETS. However, the schedule for launching the ETS is unclear.					
Thailand (ETS)	ETS	Under consideration	TBC	Thailand is currently studying which type of carbon pricing would be suitable. As part of this process, Thailand has started a voluntary ETS at the end of 2014, with Phase 1 (2015-2017) testing MRV system and Phase 2 (2018-2020) testing the registry and allocation systems. Phase 2 will be an ETS					

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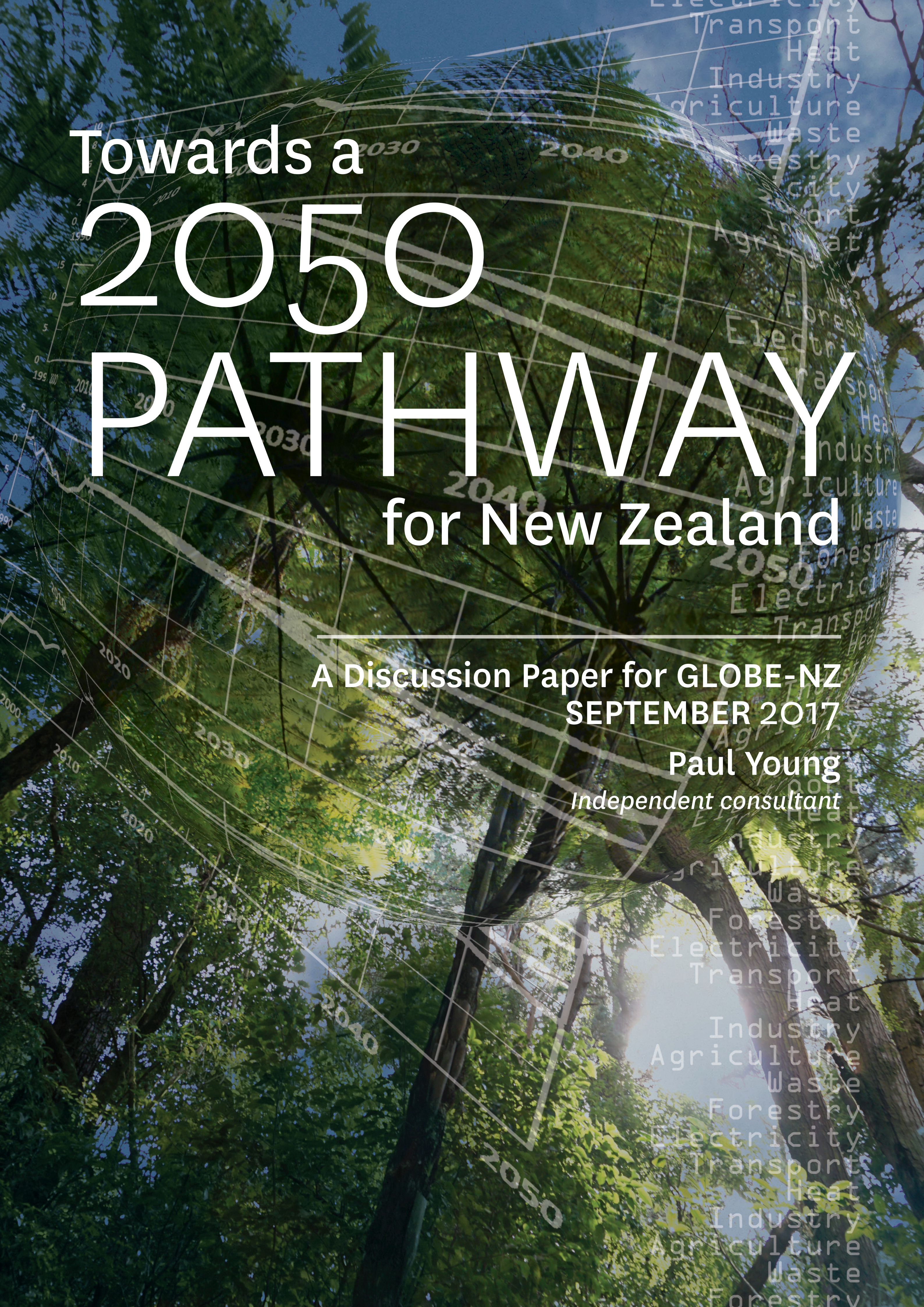
				simulation covering various industrial sectors.					
Tianjin pilot ETS	ETS	Implemented	2013	The Tianjin pilot ETS is a key instrument to lower the costs to achieve the green low-carbon development goals of the city of Tianjin and raise awareness on GHG emission control. The cap-and-trade system also aims to promote economic development and industrial optimization and upgrading.	Tianjin	55%	The Tianjin pilot ETS applies to CO_2 emissions from the industry, power and buildings sectors.	Not applicable	The Tianjin pilot ETS is to be merged into the national ETS under unified rules and a detailed transition plan is under development.
Tokyo CaT	ETS	Implemented	2010	The Tokyo Cap-and-Trade Program is a baseline-and-credit system and Japan's first mandatory ETS. The Tokyo CaT introduced mandatory emission reduction targets for large emitters.	Tokyo	20%	The Tokyo CaT applies to energy-use related CO_2 emissions from the industry, power and buildings sectors.	100%Estimated based on overlap with: Japan carbon tax	The Tokyo CaT is linked to the Saitama ETS and operators can use credits from the Saitama ETS to meet their compliance.
Turkey (ETS)	ETS	Under consideration	TBC	Turkey adopted MRV legislation in 2012 and monitoring of GHG emissions from large installations started in 2015. The PMR is supporting the implementation of the existing legislation, including the analysis and choice of appropriate market-based mechanisms, including a possible ETS.					
UK carbon price floor	Carbon tax	Implemented	2013	The UK carbon price floor aims to reduce revenue uncertainty and improve the economics for investment in low-carbon generation for the UK electricity generation sector. The carbon price floor was introduced	United Kingdom	23%	The UK carbon price floor applies to CO_2 emissions from the power sector with some exemptions. The tax covers all fossil fuels.	100% Estimated based on overlap with: EU ETS	The tax rate under the Carbon Price Floor depends on the EU ETS price.

Name of the initiative	Type of the initiative	Status of the initiative	Year of implementation	Description of the initiative	Jurisdictions covered	Coverage of jurisdiction's GHG emissions	Sectors and/or fuels covered	Overlap with other carbon pricing initiatives	Relation to other carbon pricing initiatives
				because the EU allowances price has not been stable, certain or high enough to encourage sufficient investment in low-carbon electricity generation in the UK.					
Ukraine (ETS)	ETS	Under consideration	TBC	The Ukrainian Government published a concept ETS legislation in September 2015. The legislation aims to establish an ETS which is in line with the EU ETS from 2017, with a goal to join the EU ETS in 2019.					
Ukraine carbon tax	Carbon tax	Implemented	2011	The Ukraine carbon tax was introduced in the Ukrainian Tax Code as an environmental tax on air pollution from stationary sources.	Ukraine	71%	The Ukraine carbon tax applies to CO_2 emissions from stationary sources, so mainly the industry, power and buildings sectors. The tax covers all fossil fuels.	Not applicable	Not applicable
Washington CAR	ETS	Implemented	2017	The Clean Air Rule (CAR) in the US state Washington entered into force in 2017, establishing a baseline-and-credit system. The Washington CAR aims to reduce carbon emissions to do the state's part to help slow climate change.	Washington	67%	The Washington CAR applies to GHG emissions from the industry, power, transport, waste and buildings sectors, and include industrial process emissions.	Not applicable	Operations can use emission units from approved ETSs outside Washington state to meet their compliance obligations. Which ETSs will be approved are to be determined.

Note: Information is current as of 1 April 2017.
Source: World Bank (2017)



Towards a 2050 PATHWAY for New Zealand

A Discussion Paper for GLOBE-NZ
SEPTEMBER 2017

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EXECUTIVE SUMMARY

Under the Paris Agreement, New Zealand has committed to be part of a global effort to reach net zero greenhouse gas emissions in the second half of the century. In 2016, GLOBE-NZ commissioned economics consultancy Vivid Economics to conduct a study of New Zealand's potential to achieve this goal domestically. Vivid's report, *Net Zero in New Zealand: Scenarios to achieve domestic emission neutrality in the second half of the century*, was released in March 2017. It presents four distinct scenarios, as snapshots in the year 2050. Three of these scenarios – Resourceful, Innovative and Net Zero 2050 – put New Zealand on track to the net zero goal.

This paper builds on Vivid's work by exploring in greater detail what the transition might look like between now and 2050. Using a sector-by-sector backcasting approach, I have sought to create realistic transition paths consistent with Vivid's scenarios. Together, these provide a broad-banded indicative pathway towards domestic emissions neutrality, with the boundaries defined by Resourceful and Net Zero 2050. Table 1 shows the 2050 emissions profile of those two scenarios compared with 2014. The pathway range for net emissions in 2050 is 1.8–20.2 $MtCO_2e$.

To facilitate this work, Vivid provided the emissions calculator they developed to calculate the emissions outcomes of the assumptions underpinning their scenarios. I analysed the calculator and Vivid's report to identify the key drivers of emissions and calculation methods used in each sector. I then developed trajectories for each individual driver between 2014 and 2050, and modified the calculator accordingly.

The resulting sectoral emissions paths show distinct shapes and rates of change. This reflects different underlying factors such as the key drivers of emissions, current trends, and timeframes for technology adoption. These paths do not encompass the full range of possibilities for how the transition could occur; for example, accelerated or delayed action in different areas.

The resulting gross and net emissions paths are shown in Figure 1. Both peak in 2018 and fall thereafter. The fastest rate of gross emissions reductions occurs in the 2020s, with assumed growth in adoption of electric vehicles and the introduction a methane vaccine or inhibitors in agriculture. Relative to 2014, the paths see gross emissions reduced 10-20 per cent by 2030 and 30–53 per cent by 2050. Thanks to growth in carbon sequestration from forestry, net emissions continue to reduce rapidly to 2050. Relative to 2014, net emissions are 13-25 per cent lower by 2030 and 69–97 per cent lower by 2050.

Under the Paris Agreement, New Zealand has set a 2030 emissions target of 30 per cent below the 2005 gross emissions level. The target applies to net emissions using the proposed "Modified Kyoto" accounting method for forestry sequestration and emissions. For compliance, this target will be converted into a "carbon budget" for the 2021-2030 period.

Compared to a provisional carbon budget of 594 $MtCO_2e$, total gross emissions for the 2021–2030 period range from 729–774 $MtCO_2e$ under the emissions paths shown. Total net emissions range from 584-629 $MtCO_2e$, suggesting the carbon budget could be met domestically. However, due to differences between the forestry accounting method used by Vivid and the method the New Zealand Government intends to apply to the 2030 target, the net emissions quantities cannot be directly compared like this.

This paper also extends the analysis beyond 2050 to explore if and when net zero might be achieved under the different scenario paths (Figure 1 shows the emissions paths to 2070). Under the extended set of assumptions used, neither Resourceful nor Innovative would in fact reach net zero emissions. This is because many current emissions sources (such as light vehicles and low-grade heat) are close to completely decarbonised by mid-century so cannot yield meaningful further reductions, while emissions from several other sources (such as non-road transport) remain flat or growing. Due to the combined effect of slowing reductions in gross emissions and declining sequestration from forestry, net emissions begin to rise again from around 2060. Even the Net Zero 2050 scenario would only manage to keep net emissions below zero temporarily. This highlights problems with heavy reliance on forestry sequestration rather than permanent gross emissions reductions, and the need to explore further long-term mitigation measures.

The results here provide a broad-banded indicative pathway towards domestic emissions neutrality, which GLOBE-NZ could use for the basis of further conversation and analysis. This indicative pathway serves as a sound and consistent starting point, but does not span the full range of possibilities for how the transition could occur.

I conclude with the following recommendations to GLOBE-NZ:

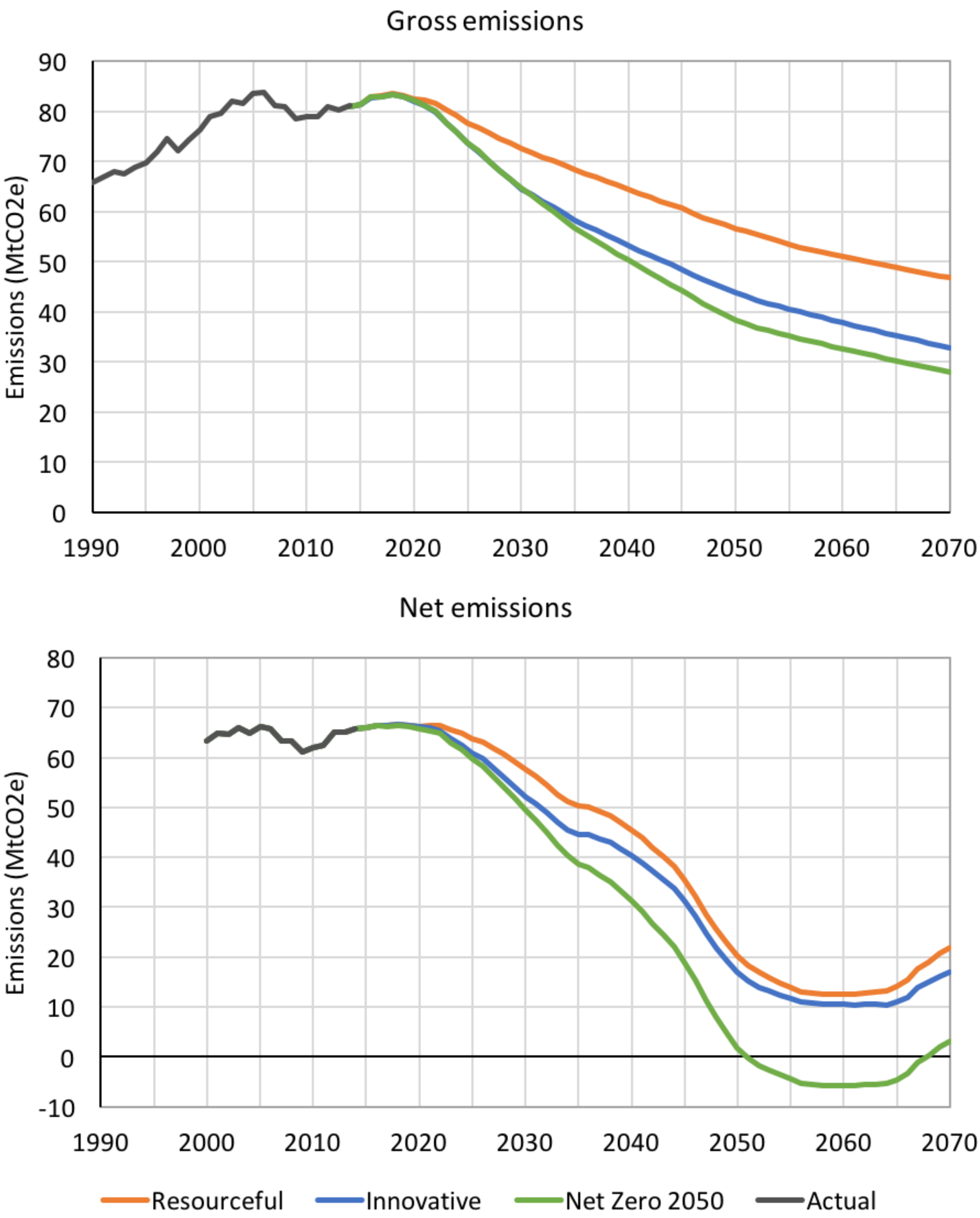
1. Forestry sequestration estimates should be reviewed.
2. Consider additional elements beyond emissions levels in defining a pathway to domestic emissions neutrality.
3. Continue to consider and explore emissions reduction opportunities going beyond those featured in Vivid's scenarios.
4. Explore the potential for interactive tools to assist in further development and communication of a pathway to domestic emissions neutrality.

TABLE 1: EMISSIONS PROFILES IN 1990, 2014 AND 2050

		1990	2014	2050	
				Resourceful	Net Zero 2050
Energy	Electricity	3.5	4.2	3.3	0.7
	Transport	8.8	14.1	5.8	3.9
	Other fossil fuels	10.2	11.9	8.3	3.0
	Fugitives	1.3	2.0	2.8	1.8
	Sub-total	**23.8**	**32.1**	**20.2**	**9.4**
Industry	Mineral	0.6	0.8	1.1	1.1
	Chemical	0.2	0.4	0.3	0.0
	Metal	2.7	2.3	2.5	0.0
	HFCs/solvents	0.1	1.6	0.3	0.3
	Sub-total	**3.6**	**5.2**	**4.2**	**1.4**
Agriculture	Enteric fermentation	26.3	28.6	18.7	14.3
	Manure management	0.7	1.3	1.0	0.9
	Soils, liming, urea	7.3	9.7	8.8	9.5
	Other	0.0	0.0	0.0	0.0
	Sub-total	**34.4**	**39.6**	**28.5**	**24.7**
Waste	Land	3.8	3.7	3.3	2.2
	Water	0.3	0.4	0.5	0.5
	Sub-total	**4.1**	**4.1**	**3.8**	**2.7**
Gross emissions		**65.8**	**81.1**	**56.6**	**38.3**
Of which long lived (CO2 and N2O)				*32.4*	*20.0*
Forestry/LULUCF		**-28.9**	**-24.4**	**-36.4**	**-36.5**
Net emissions		**36.9**	**56.7**	**20.2**	**1.8**
Of which long lived (CO2 and N2O)		*3.7*	*20.2*	*-4.0*	*-16.5*

Note: All values are rounded to one decimal place, so totals do not all sum correctly.

FIGURE 1: GROSS AND NET EMISSIONS PATHS



1 INTRODUCTION

1.1 GLOBAL CONTEXT: THE PARIS AGREEMENT AND THE 2050 PATHWAYS PLATFORM

The world has begun on a journey to a net zero emissions future to address the grave threat that climate change poses to life on Earth. The Paris Agreement, now ratified by 160 countries including New Zealand, 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*"*. In order to meet this global temperature goal, the Agreement aims to "reach 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".

Creating a net zero emissions world means transformational change to global energy and food systems. This requires proactive and comprehensive long-term planning towards the end goal. The Paris Agreement recognises this need in Article 4.19, which states:

> *All Parties should strive to formulate and communicate long-term low greenhouse gas emission development strategies, mindful of Article 2 taking into account their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.*

So far, France, Benin, the United States, Mexico, Germany and Canada have formally communicated long-term strategies through the UN.[1] New Zealand is expected to do so by 2020.[2]

At COP22 in Marrakech in 2016, a group of countries and other actors launched a complementary initiative called the 2050 Pathways Platform. The launch announcement describes it as follows:[3]

> *The platform will support countries seeking to develop long-term, deep decarbonization strategies, including through the sharing of resources (finance, capacity building), knowledge and experiences. It will also build a broader constellation of cities, states, and companies engaged in long-term low-emissions planning of their own, and in support of the national strategies. Essentially, it will be a space for collective problem-solving.*
>
> *2050 pathways are a way to backcast and extrapolate from the long-term goal of reaching the balance between the sources and sinks of GHG emissions, and look at*

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[1] http://unfccc.int/focus/long-term_strategies/items/9971.php
[2] New Zealand Government. 2016. *Paris Agreement National Interest Analysis*. Wellington: New Zealand Government.
[3] http://newsroom.unfccc.int/media/791675/2050-pathway-announcement-finalclean-3.pdf

the ways in which we can grow our economies and businesses, and meet our citizens and customer's needs within the constraints of the deep GHG emission reductions by mainstreaming climate actions within socio-economic development strategies.

New Zealand is listed as one of the 22 countries to "have started or be about to start a process of preparing a 2050 pathway".

1.2 DOMESTIC CONTEXT: GLOBE-NZ AND *NET ZERO IN NEW ZEALAND*

GLOBE New Zealand (GLOBE-NZ) is a cross-party working group established in October 2015 that involves Members of Parliament from all parties. GLOBE-NZ is a chapter of the Global Legislators Organisation for a Balanced Environment (GLOBE). The international organisation brings together parliamentarians from over 80 countries, with a focus on implementing laws in pursuit of sustainable development. GLOBE-NZ's purposes include: "The promotion of global, regional and national policy processes for climate and environmental protection"; and "The promotion of a cross-party discussion and cooperation on the environment, climate protection and nature conservation, as well as sustainable development."[4]

GLOBE-NZ commissioned economics consultancy Vivid Economics (referred to henceforth simply as "Vivid") to conduct a study of New Zealand's potential to achieve net zero emissions. Vivid's report, *Net Zero in New Zealand: Scenarios to achieve domestic emission neutrality in the second half of the century*, was released in March 2017. This report is, in Vivid's own words, "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". It identifies and presents analysis on four scenarios, three of which are consistent with the goal of net zero emissions in the second half of the century. The scenarios are presented as snapshots in the year 2050, with the trajectory between now and then undefined.

In July 2017, GLOBE-NZ agreed on a Statement of Collaborative Purpose. This statement includes the following next steps to build on Vivid's work:

- *Accept, as the basis for discussion as to their respective merits, the Innovative and Resourceful scenarios identified for New Zealand; and the Net Zero 2050 scenario as a serious aspirational goal;*

- *Plan to develop, through further expert advice, an indicative pathway (bounded by quantitative ranges) towards domestic emissions neutrality, having regard to the Report's conclusions and recommendations;*

- *On the basis of such an indicative pathway and at an appropriate time, commence a dialogue within our group on policy measures, with an appropriate combination of market, regulatory and educational measures, to ensure a timely and just transition to a net-zero or a low-carbon economy by 2050.*

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[4] GLOBE New Zealand. 2017. *Statement of Collaborative Purpose*.

1.3 SCENARIOS, PATHWAYS AND STRATEGIES: CONCEPTS AND TERMINOLOGY

What exactly is a 'pathway' in the context of a country's climate change response? It may help to try and clarify this and other key terms and concepts.

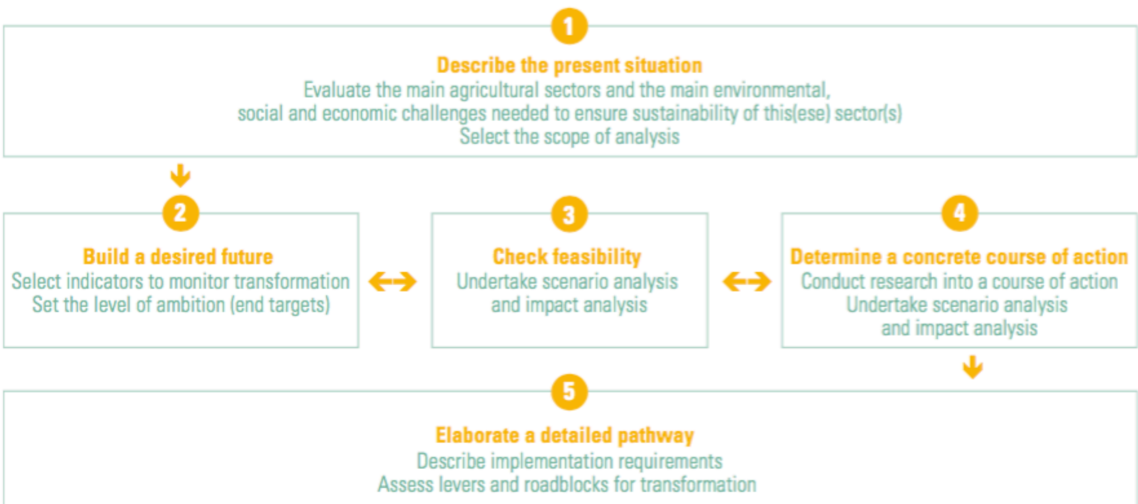
'Scenario' has a fairly precise and commonly held meaning. Vivid adopts the definition used by the Intergovernmental Panel on Climate Change and others: "a plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key relationships and driving forces".

'Pathway' is a more ambiguous and divergent term. Generally, pathways focus on transition over time and may contain dynamic and adaptive elements (whereas a scenario tends to be static and rigid). A pathway might have a number of potential outcomes depending on how options develop over time. Finally, whereas scenarios tend to focus on 'what' (tangible changes within the system and the consequences of those changes), pathways tend to also look at 'how' (approaches to drive the desired changes and monitor progress).

The relationship between a pathway and a strategy is unclear; it seems that these terms are somewhat overlapping and often used interchangeably.

The Agricultural Transformation Pathways Initiative (ATPi) develops toolkits for and works with governments to build national pathways aligned with the Sustainable Development Goals.[5] Figure 2 is a diagram illustrating the ATPi general methodological framework. This is an iterative process to develop a pathway for moving from the present to a desired future. Scenario analysis plays a key role in this process.

FIGURE 2: PATHWAYS METHODOLOGY DEVELOPED BY THE AGRICULTURAL TRANSFORMATION PATHWAYS INITIATIVE



Source: Schwoob, M.-H. et al. 2016.

[5] Schwoob, M.-H. et al. 2016. Agricultural Transformation Pathways Initiative - Summary, IDDRI & Rothamsted Research.

Transformation pathways do not only provide aggregate end targets (such as average emissions reduction), but also translate into a concrete image of what future activity and society might look like. The consistency and desirability of such a vision can then be discussed and questioned, and a detailed sequence of feasible actions developed.
– Agricultural Transform Pathways Initiative (2016)

Based on a brief assessment of the ATPi methodology and some of the long-term low emission development strategies that have been communicated to the UN, a 2050 pathway for New Zealand might either include or sit alongside elements such as:

- Goals;
- Guiding principles;
- Targets and milestones (e.g. sectoral emissions target);
- Key indicators (potentially in the form of a dashboard);
- Identification of enabling conditions (e.g. technology developments) and key decision points;
- Identification of barriers to and levers for change;
- A learning and evaluation process.

A further idea worth consideration is to develop transformative pathways for each sector, within an overarching framework and national pathway.[6] Such sectoral pathways could combine emissions targets with other goals and principles to form a broader vision and integrated strategy.

1.4 PURPOSE OF THIS PAPER

Vivid's *Net Zero in New Zealand* report provides a foundation for developing a national 2050 pathway. This paper builds on Vivid's work by exploring in greater detail what the transition might look like between New Zealand today and the scenarios for 2050.

The main objective was to develop a broad-banded indicative pathway that spans the three scenarios that place New Zealand on track to net zero emissions in the second half of the century. Acknowledging the above discussion on the range of elements that may form part of a 2050 pathway, this paper is more narrowly focused on the emissions path.

The paper begins with a brief overview of the three scenarios used. It then details, sector by sector, the method and assumptions used to develop plausible trajectories for various drivers of emissions between 2014 and 2050. It then presents and analyses indicative emissions paths by sector and for New Zealand as a whole. It concludes with recommendations for further work.

[6] Germany's *Climate Action Plan 2050* uses an approach like this.

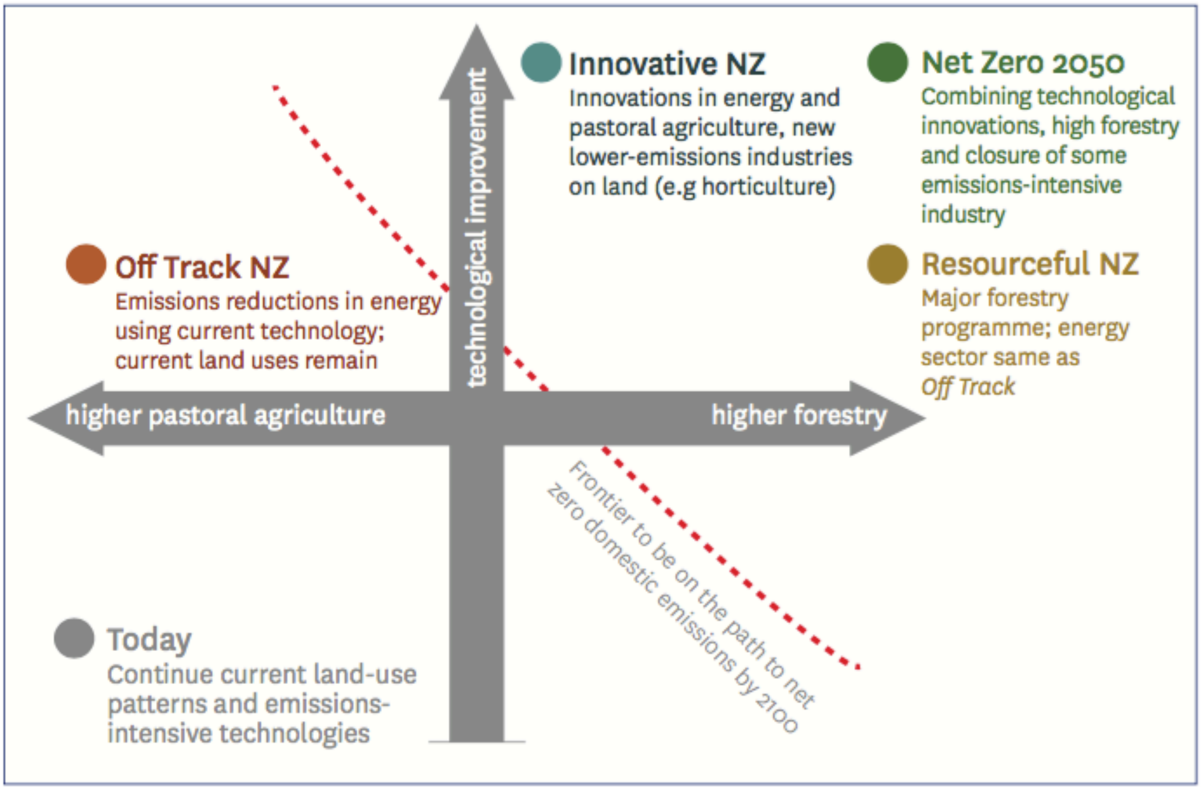
2 SCENARIOS FROM *NET ZERO IN NEW ZEALAND*

Vivid Economics developed four scenarios for its report, *Net Zero in New Zealand*. As Figure 3 shows, these differ along two key dimensions: the degree of technological improvement, and land-use patterns. To get on track to net zero emissions in the second half of the century, it is necessary to move towards the top-right corner of this diagram. As its name makes clear, the Off Track NZ scenario does not meet that condition and it is therefore excluded from further analysis in this paper.

2.1 INNOVATIVE

The Innovative scenario envisages a future where technological advances in the energy and agriculture sectors are strong and New Zealand takes major advantage of these through fast adoption. The key changes it sees by 2050 include: widespread electrification of both and light and heavy vehicles, and of heat and industrial energy use; an almost completely renewable electricity system, aided by improvements in energy storage and grid flexibility; substantial freight mode shift from road to rail; energy efficiency gains; low emissions farming practices; and the successful development and adoption of a methane vaccine for ruminant livestock. Alongside this, a diversification in land use patterns occurs in favour of more forestry and horticulture, with a reduction in stock numbers compared with today.

FIGURE 3: VIVID'S SCENARIOS AND THEIR KEY CHARACTERISTICS



Source: Vivid Economics, 2017.

2.2 RESOURCEFUL

In Resourceful, technological improvements are slower and more modest. Compared with Innovative, less progress is made in several areas including vehicle and heat electrification, renewable electricity, and freight mode shift. Some of the mitigation opportunities in Innovative – including the methane vaccine and electrification of high temperature heat – are not available at all by 2050. To compensate for this, Resourceful sees a more radical shift towards forestry, planting the maximum amount of land generally deemed suitable by 2050. However, livestock numbers are also higher in Resourceful due – enabled by a higher stocking rate for dairy.

2.3 NET ZERO 2050

Net Zero 2050 combines the technological advances of Innovative with the land use patterns of Resourceful. In addition, it assumes carbon neutrality in, or the closure of, some emissions-intensive industries (steel and aluminum manufacturing and petroleum refining).[7] Together this makes a higher ambition scenario that drives net emissions close to zero by 2050. Net Zero 2050 was not considered in detail by Vivid, and the report did not provide emissions data, given its similarities to elements of the other scenarios.

2.4 A BROAD-BANDED INDICATIVE PATHWAY: THE CONCEPT

In this paper, I take the Resourceful and Net Zero 2050 scenarios to define the bounds of a "broad-banded indicative pathway" towards net zero emissions in the second half of the century. The analysis and graphs in the following chapters treat each scenario individually, but conceptually we can think of these as spanning a range of potential paths in between the extremes.[8]

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[7] The industry closure assumption was also used as a sensitivity case to create "low industry" variations of the other scenarios.

[8] One point of caution is that if we were to combine the higher end of the gross emissions range (Resourceful) with the lower end of the forestry range (Innovative), this would create a new scenario with net emissions outside of the range spanned by Vivid's scenarios. This needs to be taken into account if combining numbers from different sectors.

3 DEVELOPING SECTORAL EMISSIONS PATHS

In order to develop credible emissions paths consistent with Vivid's scenarios, it is necessary to analyse each sector individually. Each sector has distinct characteristics, such as the key drivers of emissions; technological and socioeconomic dynamics; and typical asset lifetimes and turnover rates. These factors can affect the timing of emissions reductions and thus the shape of the curve between now and 2050.

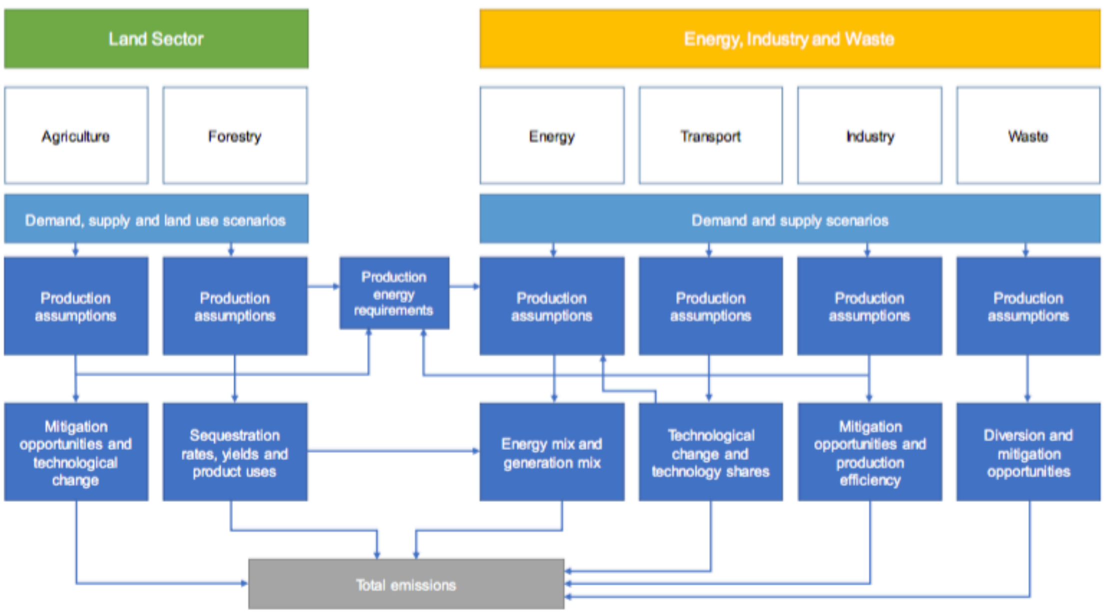
This chapter presents the general method used to develop sectoral paths consistent with Vivid's scenarios, followed by the specific approach used for each sector.

3.1 GENERAL METHOD

To facilitate this work, the Vivid team provided the calculator tool they developed to calculate the emissions outcomes of the assumptions underpinning their scenarios. The calculator is described in the *Net Zero in New Zealand* technical report and summarised in the schematic below (Figure 4).

I analysed the calculator and the technical report to identify the key drivers[9] and calculation methods used in each sector. I then developed trajectories for each individual driver between 2014 and 2050, aiming to be as realistic as possible. This was done case by case depending on: the logic and external sources used by Vivid; knowledge of the dynamics of the driver in question; and information on recent trends. Finally, I modified the calculator spreadsheet accordingly to produce the complete emissions time series for each sector.

FIGURE 4: OVERVIEW OF VIVID ECONOMICS' CALCULATOR



Source: Vivid Economics, 2017.

[9] Some examples of drivers are livestock numbers (in agriculture), fuel efficiency (in transport) and electrification level (in transport and heat). Table 5 lists all drivers along with Vivid's scenario assumptions.

3.2 ELECTRICITY

The key drivers of electricity emissions are: electricity demand, generation mix, and the emissions intensity of geothermal generation. Table 5 shows Vivid's assumptions for these and all other drivers in detail.

Vivid sourced the 2050 generation mix in Resourceful directly from one of the Electricity Demand and Generation Scenarios published by MBIE.[10] They constructed the generation mix in Innovative to be similar, with the main difference being further reductions in coal and gas replaced with wind. To maintain consistency with the sources of Vivid's assumptions, in Resourceful I used the complete time series from MBIE's scenario.[11] In Innovative, I modified this by eliminating coal generation from 2023 and reducing the gas generation proportion linearly from 2025 to 2035. The resulting generation mixes to 2050 are shown in Figure 5.

Annual electricity demand was calculated as described in Table 5. For geothermal emissions intensity, and additional energy efficiency improvements in Innovative, I used an annual rate of change as per Vivid's description.

3.3 TRANSPORT

The transport sector covers all domestic transportation (road, rail, sea and air) but excludes international flights and shipping. The key drivers of transport emissions are: travel demand, vehicle or mode efficiencies, modal shift, and vehicle electrification.

For most of these drivers, I used a fixed annual percentage rate of change. For freight mode shift, I used a linear trajectory.

Vehicle electrification was modelled differently. I developed a simple fleet model to create plausible trajectories for battery electric vehicle (BEV) uptake consistent with Vivid's assumed levels in 2050. The model assumed fixed annual quantities of vehicles entering and exiting the fleet, calibrated to average values over the last 10-15 years. For each scenario, I fitted an idealized "S-curve" for the EV market share (of vehicles entering the fleet) in order to match the approximate market share in 2016 and the assumed fleet electrification level in 2050.[12]

This model is necessarily simple, but I would expect it to give realistic results for the light vehicle fleet. However, it is less realistic for heavy vehicles and results should only be taken as broadly indicative.[13] Also, I have not considered disruptive scenarios where – due to changes in technologies, behaviours and policies – vehicle turnover accelerates and/or new

[10] Global Low Carbon scenario is the scenario used.
[11] I modified this slightly by assuming a fixed percentage of gas generation from 2035 onward.
[12] Strictly speaking this is a travel-weighted electrification level, or it assumes that all vehicles are travelling the same distance each year.
[13] A more realistic uptake model for heavy vehicles would, for example, disaggregate the fleet by size and/or typical usage cycle, to identify the types of vehicles more readily electrified.

ownership models dominate. The model therefore represents a conservative view of change.

The resulting trajectories are presented in Figure 6. This shows that, under the stated assumptions, all light vehicles entering the fleet would need to be battery electrics by around 2035 in Innovative and around 2040 in Resourceful. All heavy vehicles entering the fleet would also need to be electric before 2045 in Innovative (subject to the above caveats).

FIGURE 5: ELECTRICITY GENERATION MIX IN RESOURCEFUL (TOP) AND INNOVATIVE (BOTTOM)

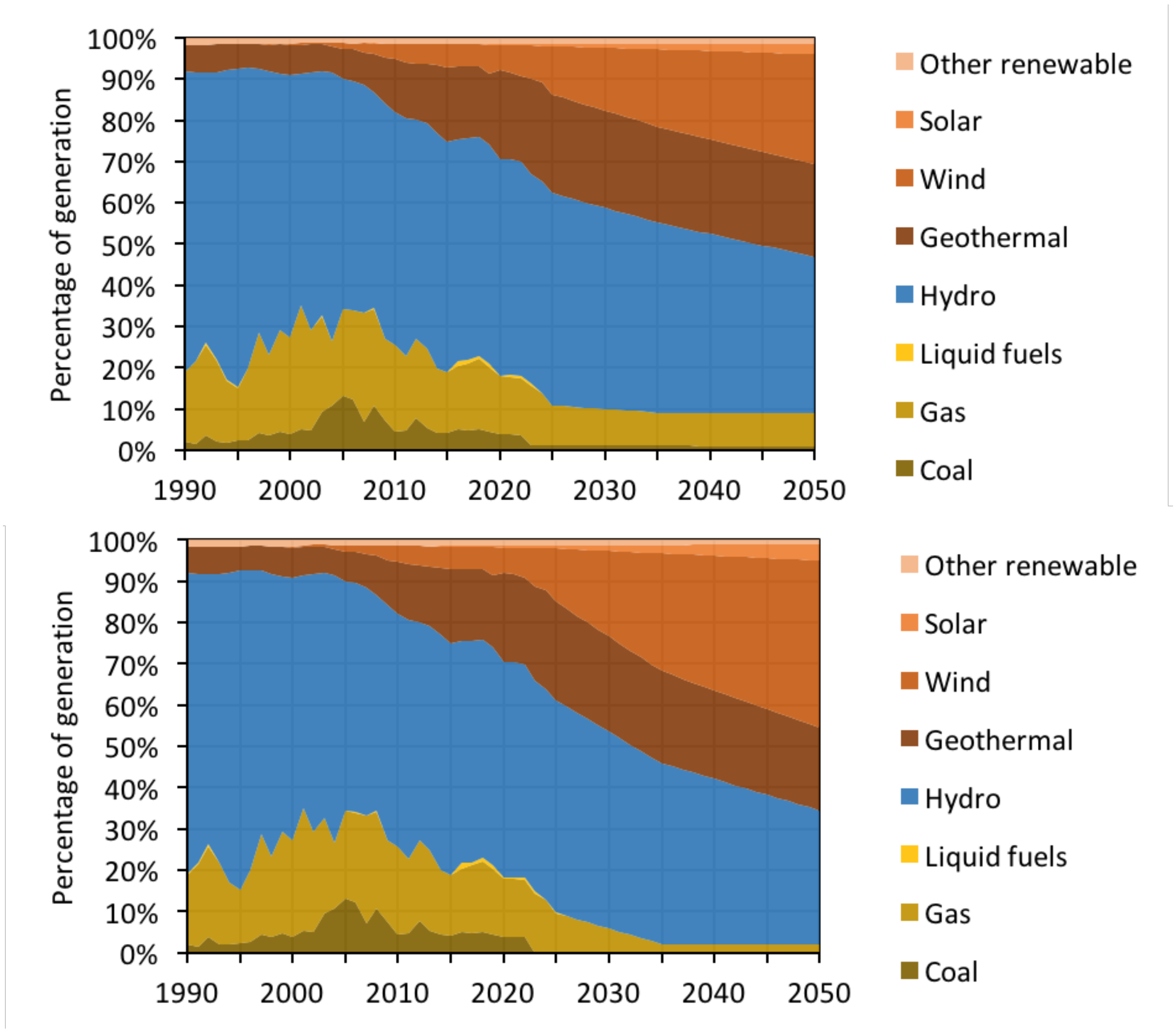


FIGURE 6: BATTERY ELECTRIC VEHICLE (BEV) SHARE OF NEWLY REGISTERED VEHICLES AND TOTAL FLEET FOR LIGHT VEHICLES (TOP) AND HEAVY VEHICLES (BOTTOM)

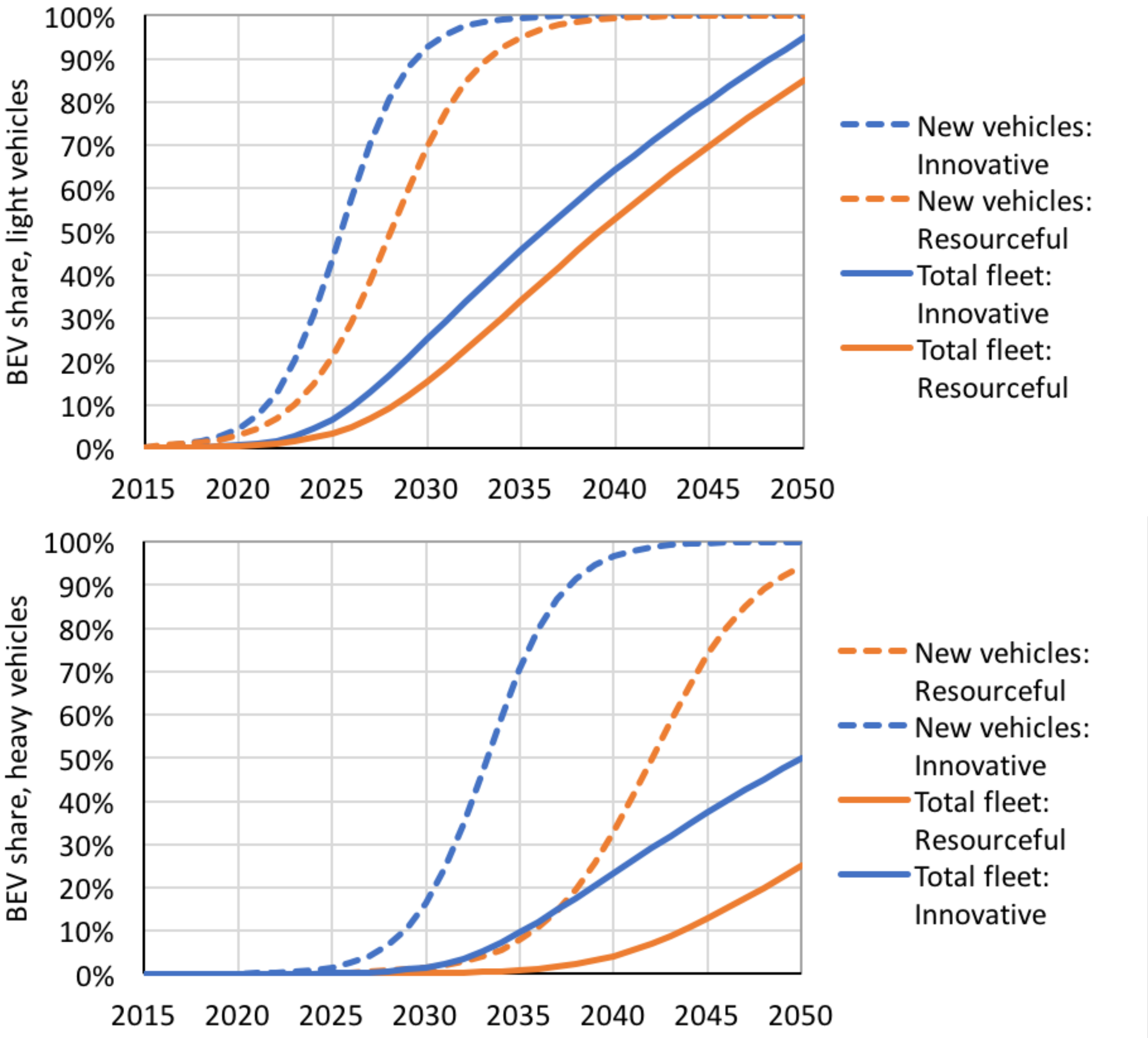
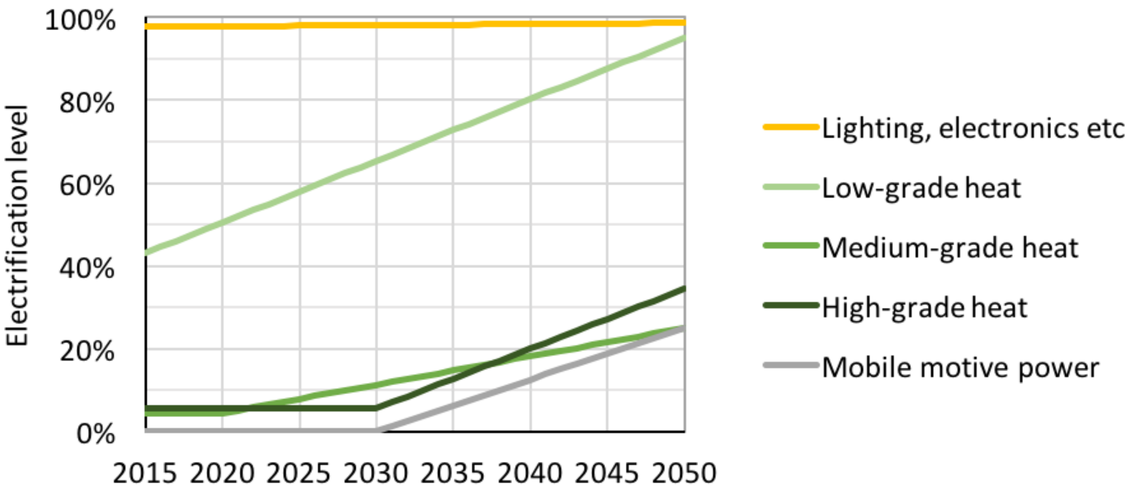


FIGURE 7: ELECTRIFICATION LEVEL OF ENERGY END USES IN THE INNOVATIVE AND NET ZERO 2050 SCENARIOS



3.4 OTHER FOSSIL FUELS

"Other fossil fuels" encompasses all combustion of fuels for energy outside of the electricity and transport sectors. The vast majority of this is to produce heat for use in buildings and industry. The key drivers of emissions are: energy demand (including efficiency gains); electrification; and fuel switching to biomass.

Annual energy demand is calculated using a baseline scenario from MBIE and feedbacks with other sectors, as described in Table 5. I have used fixed annual energy efficiency improvement rates where applicable.

I have assumed a linear increase in the electrification level, but with different start dates for the different energy end uses. The level begins increasing immediately for low-grade heat, from 2020 for medium-grade heat, and from 2030 for high-grade heat and mobile motive power. Figure 7 shows the resulting electrification paths in Innovative.[14]

These assumptions aim to reflect Vivid's assessment that electrification of high-grade heat and off-road vehicles is currently high cost and dependent on technology breakthroughs. Ideally, the paths would take into account information such as asset lifetimes and replacement timetables. A more sophisticated treatment was not possible due to time constraints, and would likely be challenging due to a lack of data in this area.

Vivid assumed that uptake of bioenergy is targeted solely at medium-grade heat in the pulp, paper, wood and agricultural processing industries. Here I have assumed linear growth in uptake from 2014.

3.5 FUGITIVE EMISSIONS

Fugitive emissions in New Zealand result mainly from natural gas production and distribution, use of geothermal energy and coal mining. The key drivers are geothermal energy use and emissions intensity; and levels of natural gas production, oil refining and coal mining.

Geothermal energy use is calculated from other assumptions, and I use a constant annual rate of emissions intensity improvement.

Emissions from oil refining and coal mining are scaled with the level of industrial activity (see Section 3.6). Coal mining is assumed to be linked to iron & steel production.

Vivid assumed that emissions from natural gas production scaled with the baseline non-electrical energy demand. This seems to ignore the substantial electrification of heat in the scenarios, which would presumably reduce natural gas usage below the baseline level. However, I have kept Vivid's assumption and extended this over the complete time series

[14] Aluminium manufacturing and iron and steel manufacturing are not shown as these are held constant at 100% and 0% electrification, respectively.

3.6 INDUSTRIAL PROCESSES AND PRODUCT USE

This sector covers all non-combustion emissions in the production of minerals (e.g. cement and lime), chemicals (e.g. ammonia and methanol), and metals (e.g. aluminium, iron and steel). It also includes use of industrial gases (mainly hydrofluorocarbons, HFCs) as refrigerants and solvents. The key drivers of emissions are levels of industrial activity, process efficiency, and level of HFC use.

Vivid assumed that mineral production scales with population growth, while production of chemicals and metals scales with baseline non-electrical energy demand. I extended the same assumption over the whole time series.

The chemical and metal industries are assumed to cease operating sometime before 2050 in Net Zero 2050 (and in the "low industry" variations of the other scenarios). The timing of potential closures is completely unknown, but here I have assumed this does not occur before 2030. I have used a simple linear phase out of activity in the affected industries between 2030 and 2050. In reality, the trajectory would be "lumpy" given we are dealing with a small number of reasonably large firms. The linear phase out should be taken as a stylised or smoothed approximation.

On HFCs, New Zealand is one of 197 countries that signed up to phase these down significantly under the Kigali Amendment to the Montreal Protocol. In May 2017, the New Zealand Government proposed and consulted on a detailed phase-down timetable from 2019 to 2037 to be set in regulation.[15] I have used this exact timetable, with a linear extension after 2037 to meet Vivid's 2050 value.

3.7 AGRICULTURE

The key drivers of agricultural emissions are: livestock numbers, production per animal, and emissions intensity improvements through better practice and adoption of new technologies.[16]

The agriculture sector has undergone very significant changes over recent decades, as can be seen in the change in livestock numbers. Since 1995, sheep and beef cow populations have fallen by over 40% and over 30% respectively, while the dairy cow population has grown by around 60%. The reduction in dairy cow numbers in Vivid's scenarios is therefore a significant reversal of the present trend.

To try to reflect the inertia behind the growth in dairy cow numbers, I fitted curves that smoothly transition from linear growth to an exponential decline. The timing and magnitude of the peak depends on the initial growth rate (estimated at 3.3%) and the scenarios' 2050 values.

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[15] Ministry for the Environment. 2017. *New Zealand's phase down of hydrofluorocarbons to ratify the Kigali Amendment to the Montreal Protocol and associated supporting measures: Consultation document*. Wellington: Ministry for the Environment.

[16] In the calculator, stocking rate does not affect the emissions from agriculture, as stock numbers are fixed (it only affects land available for forestry).

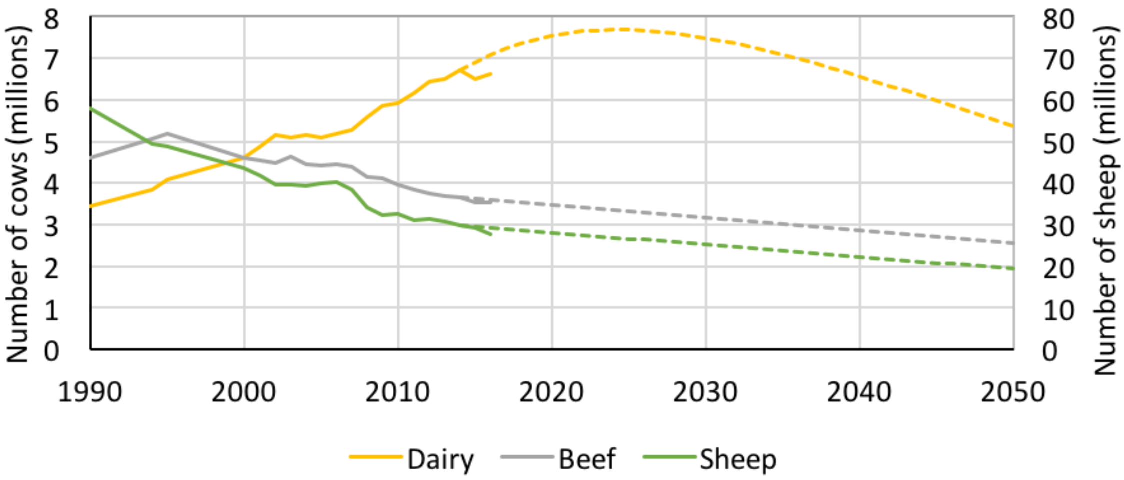
The livestock number trajectories for Innovative are shown in Figure 8, along with historical data since 1990. Here, dairy cow numbers peak at around 7.7 million in 2024 (a 15% increase from 2014). In Resourceful, the peak is slightly higher and later (7.9 million in 2026). If a slower rate of reduction were desired, this would require an earlier and/or lower peak.

For sheep and beef populations, the average rate of reduction implied by Vivid's 2050 assumptions is actually slower than what has occurred over the last five to ten years. I therefore simply used a linear reduction from 2014 to 2050.

As Vivid's scenarios and calculator tool are calibrated to a 2014 base year, I have opted to project forward from 2014 for consistency. More recent data are now available for livestock numbers; I have included these in Figure 8. Dairy cow numbers fell by 3.2% in 2015 due to drought and were still 1.2% lower in 2016 compared to 2014. Sheep and beef numbers are also tracking below all scenario trajectories. We cannot deduce much from volatile short-term movements like this. However, in the wider context, including the growing acknowledgement of environmental limits on dairy farming, these trajectories may be conservative.

For improvements in productivity and emissions intensity, I have simply assumed linear change between 2014 and 2050, except in the case of a methane vaccine or inhibitor. I have assumed that these technologies become available and are phased in from 2020, reaching the maximum adoption rate in 2030. This is the same assumption used by Reisinger and Clark in the study on which Vivid based its agriculture scenarios.[17]

FIGURE 8: LIVESTOCK NUMBERS IN THE INNOVATIVE AND NET ZERO 2050 SCENARIOS



[17] Reisinger, A. and H. Clark. 2016. *Modelling Agriculture's Contribution to New Zealand's Contribution to the Post-2020 Agreement*. Wellington: Ministry for Primary Industries.

3.8 WASTE

Waste sector emissions arise from municipal solid waste, construction and demolition waste, unmanaged landfills (including farm dumps), and wastewater. The key drivers are: population; waste quantity and diversion rates; and emissions intensities (accounting for methane capture).

I used annual population projections from Statistics NZ, and linear change in all other drivers except for emissions intensity. Waste emissions have been steadily decreasing, thanks in large part to the rate of methane capture at municipal landfills doubling since 2005.[18] Using a linear reduction in emissions intensity from 2014 to Vivid's 2050 values led to a short-term increase in waste emissions in Resourceful, which seems unlikely to occur. Instead, I assumed that emissions intensity reduced by 3% per annum up until the scenario's 2050 assumption was reached, from which point on it was held constant.

3.9 FORESTRY

Forestry sequesters carbon in the trees and on the land where they are growing. If harvested, some of the sequestered carbon remains stored in harvested wood products (HWPs). Emissions occur upon deforestation or harvest, and over time as HWPs are burnt or disposed of.[19] Generally, I use the simple term 'forestry emissions' to refer to the net sum of emissions and sequestration.[20] In the scenarios considered, forestry emissions are always net negative.

The key drivers of forestry emissions are: planting rates of exotic and native species; harvesting and deforestation; and the mix of end-uses from harvested wood (e.g. hardwood products, paper and biofuels).

Forestry emissions in a given year, such as 2050, depend on the amount and timing of planting over the last several decades. Therefore, unlike in other sectors, Vivid developed specific trajectories for new plantings and for production of HWPs, and calculated annual emissions to 2100. However, Vivid's calculation excluded sequestration from forests established before 2015. Under the chosen accounting method ("averaging"), this makes no difference to reported forestry emissions in 2050, but it does affect the earlier years. To address this, I extended the forestry calculation to start from 1990, making it suitable to use for the whole time series.

Carbon accounting for forestry is complex and – particularly for HWPs – subject to considerable uncertainty. Multiple different accounting methods exist, and the choice can have a large impact on reported emissions values in a particular year. These accounting issues are discussed further in Box 1 on p. 27.

[18] Calculated from national greenhouse gas inventory data.
[19] HWPs are modelled using a decay function.
[20] Sequestration is referred to as "removals" in national greenhouse gas inventory reports.

4 RESULTS

4.1 SECTORAL EMISSIONS PATHS

The sectoral emissions paths are presented in the graphs that follow on pages 23–25. Figure 9 shows emissions paths for the top-level sectors, except for forestry. Figure 10 shows emissions paths for the sub-sectors within energy. Figure 11 shows emissions paths for forestry.

Note that:

- The "low industry" scenario variations are labelled with an "L" and shown with dashed lines in graphs;
- In graphs where the line for Innovative is not visible, it is identical to Net Zero 2050;
- The black crosses show emissions in 2014 and 2015 according to the 2017 national inventory (published after Vivid's report). Due to ongoing revision of data and updates to methodology, the 2014 values differ from the previous year's inventory in some cases.

4.1.1 ENERGY

Total emissions from the energy sector grow slightly to 2018 and then begin to fall. The pace of reduction quickens around 2023 and the gap between Resourceful and Innovative / Net Zero 2050 begins to emerge. There is a large spread by 2050, with energy emissions in Net Zero 2050 around half what they are in Resourceful.

Figure 10 provides more insight on the changes happening within the energy sector.

Electricity[21]

Electricity emissions exhibit a short-term increase due to a surge in fossil generation from 2016–19, before falling.[22] They do not fall far in Resourceful, and in fact begin to grow again after 2025 as progress in the generation mix slows and then stalls at 91% renewable. In Innovative, emissions continue to fall until the generation mix reaches 98% renewable, assumed to happen in 2035.

Transport

In all scenarios, transport emissions plateau until around 2020 and begin reducing visibly after that. The rate of reduction begins to slow after the point when all vehicles entering the fleet are electric (around 2035 and 2040 for Innovative and Resourceful respectively). Emissions from heavy vehicles do not peak until around 2030 in Innovative and 2040 in Resourceful. In 2050, combined freight emissions (from heavy vehicles, rail and sea transport) are only 16% lower than in 2014 under Innovative, and 21% higher under

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[21] Note that by convention, emissions from geothermal generation are reported under fugitive emissions rather than electricity.

[22] These projections are taken from a scenario published by MBIE (see Section 3.2).

Resourceful. Emissions from domestic air travel are approximately flat in all cases despite strong demand growth (consistent with recent trends).

Other fossil fuels

Emissions from heat and other fossil fuel combustion also plateau until around 2020 before starting to fall. Reductions come mostly from the agricultural processing industries in Resourceful – especially dairy, which is close to decarbonised by 2050. In Innovative, there are stronger reductions across all industry categories – particularly in petroleum and chemicals, although this is still the largest emitter in 2050. In Net Zero 2050, the additional emissions reductions from 2030–50 are due to the closure of petroleum and chemicals, and primary metal manufacturing industries.[23]

Fugitive emissions

Fugitive emissions (which include those from geothermal electricity generation) continue to grow out to 2050 in both the Resourceful and Innovative scenarios. Hence while these are a small proportion of energy emissions today, they become more significant over time in these scenarios (making up roughly 15-20% of total energy emissions in 2050). The growth comes almost entirely from increased use of geothermal energy, while emissions from oil & gas and coal mining remain steady. In Innovative, assumed improvements in the emissions intensity of geothermal generation reduce the growth significantly, but there is still a net increase. In Net Zero 2050, additional reductions come from closure of oil refining and coal mines.

4.1.2 INDUSTRIAL PROCESSES AND PRODUCT USE

The industrial processes and product use emissions paths are nearly identical for Resourceful and Innovative. Emissions plateau for the rest of this decade, then reduce through the 2020s, before slowly creeping up again after 2035.

The reductions in this sector are entirely from the phase out of hydrofluorocarbon gases (HFCs) used as refrigerants. Process emissions from aluminium, steel and chemical production are virtually flat, while emissions from mineral production (mostly cement and lime) grow with population (35% growth to 2050).

In Net Zero 2050, the closure of metal and chemical industries leads to a drastic emissions reduction. To reiterate, in reality this would happen with abrupt step changes, unlike the smooth emission path used here.

[23] As discussed in Section 3.6, I have used a simple linear decrease from 2030–50 to represent the industry closures.

Figure 9: Emissions paths for top-level sectors

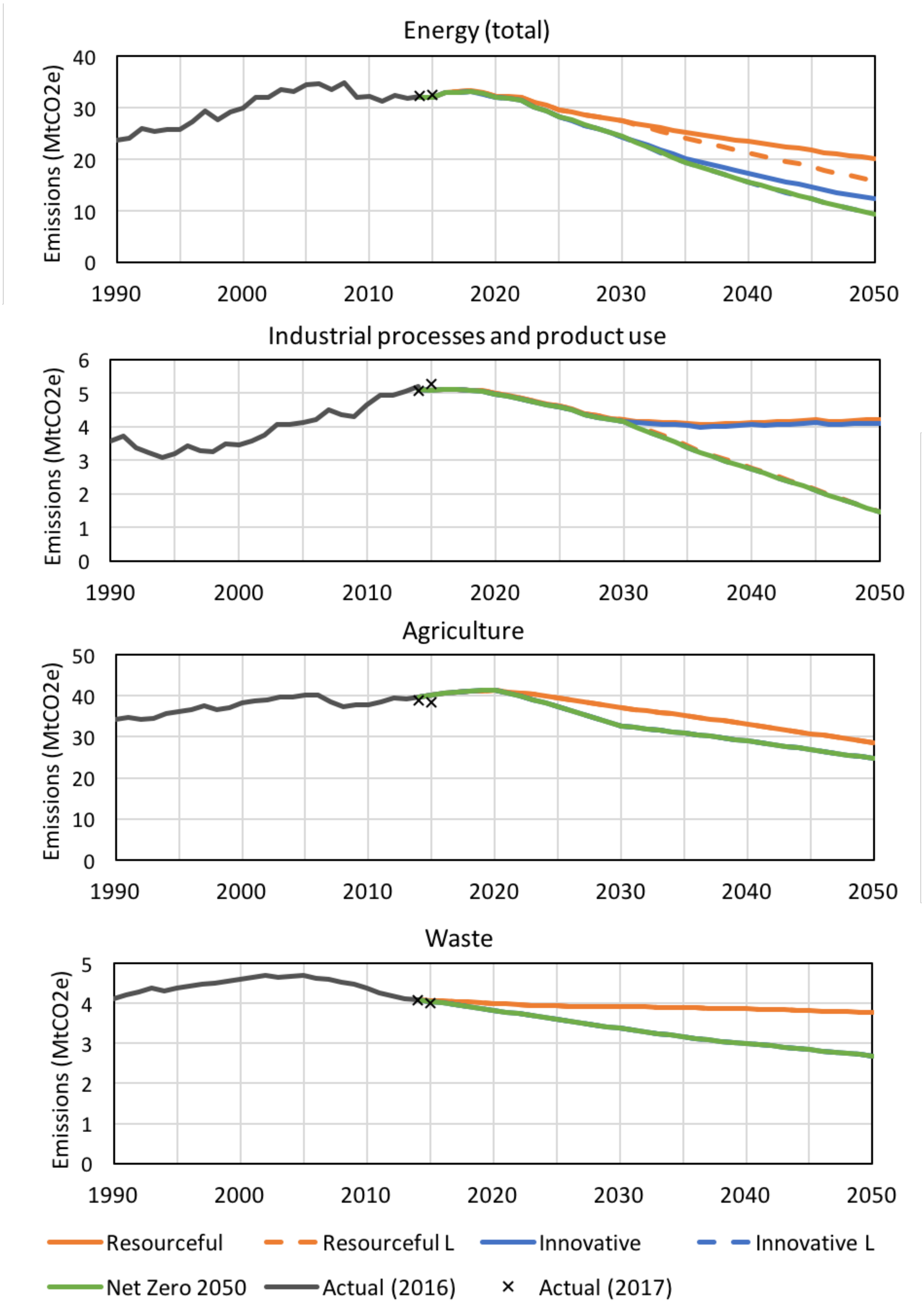


FIGURE 10: EMISSIONS PATHS FOR ENERGY SUB-SECTORS

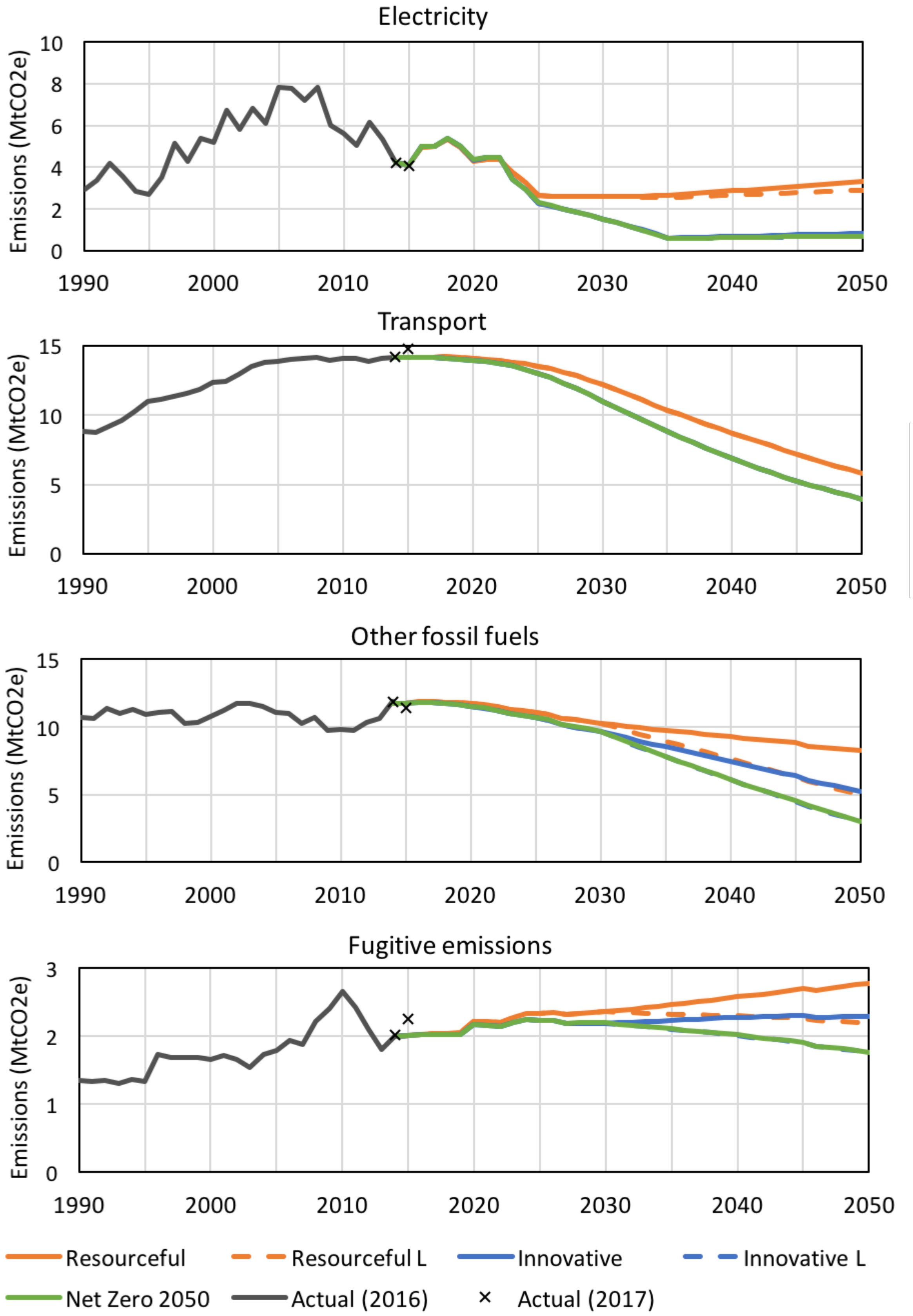
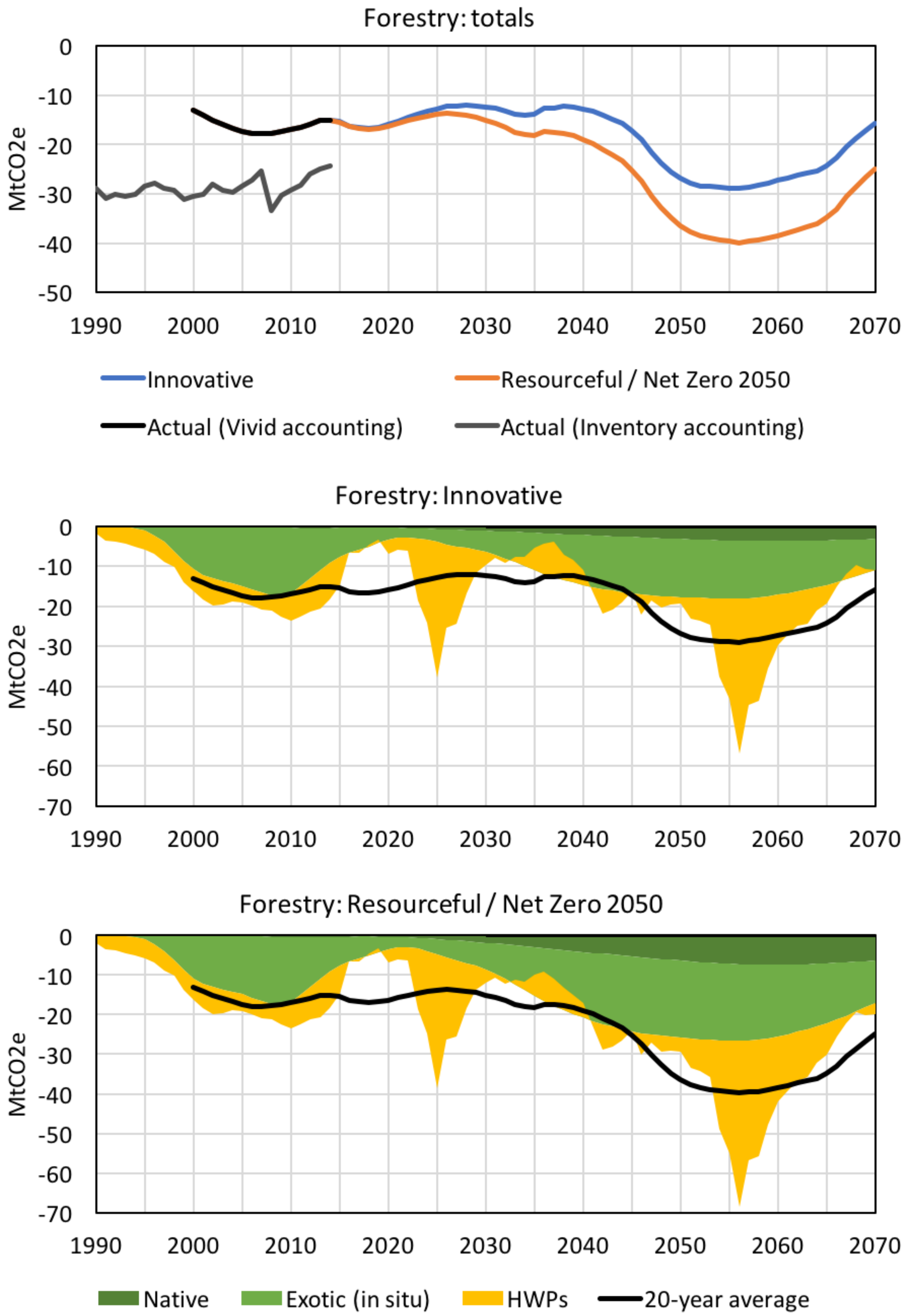


FIGURE 11: EMISSIONS PATHS FOR FORESTRY



4.1.3 AGRICULTURE

Agricultural emissions continue rising to 2020 on the back of further growth in the national dairy herd. At this point, the phase-in of a methane vaccine or inhibitor is assumed to begin (see Section 3.7), causing emissions to peak in spite of the dairy herd still growing.[24] In Innovative, the adoption of the vaccine leads to especially rapid emissions reductions through the 2020s. Both scenarios then see roughly linear emissions reductions after 2030. The scenario spread in 2050 is much smaller here than in the energy sector.

The emissions reductions in either scenario come almost entirely from enteric fermentation. Reductions in nitrous oxide emissions from animal waste are partially offset by higher emissions from horticulture (for which land use doubles in Resourceful and quadruples in Innovative). By farm type, the share of emissions from dairy farming increases in the short-term, but falls back to a similar level to today by 2050.

4.1.4 WASTE

Waste is the one sector in which New Zealand's emissions are currently on a downward trend. This continues in the emissions paths, though the rate of reduction actually slows compared to recent years (even in Innovative). Emissions are close to flat in Resourceful. Part of the reason is that reductions in solid waste emissions are partially offset by an increase from wastewater. Wastewater emissions have been nearly flat for the last 20 years, so the growth that occurs in the scenarios is questionable.

In both scenarios, more of the emissions reductions come from unmanaged waste sites than from municipal waste. The latter accounts for only 22% of total solid waste emissions in 2014, reducing to 13% in 2050 in Innovative.

4.1.5 FORESTRY

To understand the forestry emissions paths, it is important to understand the accounting method that Vivid used. This differs from the method used in New Zealand's greenhouse gas inventory, which is why there is a large difference between the inventory values and calculated values in Figure 11. The main issues around accounting are addressed in Box 1 below.

The two lower panels in Figure 11 show the emissions contributions from *in situ* sequestration and from harvested wood products (HWPs) for the different scenarios. The HWPs have a dramatic oscillating impact: peak harvesting rates lead to large negative spikes, followed by periods of net positive emissions where carbon losses from the existing pool of HWPs exceed the carbon gains from new additions. As discussed in Box 1, these extreme variations are caused by the fixed harvest age assumption in the model, which Vivid compensated for by reporting the 2040–59 average for 2050. For consistency with Vivid, I used a 20-year rolling average, shown by the black lines in the graphs. These

[24] Without either of these technologies, the peak would not occur until around 2025 when cow numbers peak.

averaged paths are presented side-by-side in the top panel of Figure 11. Note that these graphs go to 2070.

The result is that in both scenarios, total sequestration remains relatively flat to 2040 with some fluctuations (there is a gradual decline overall in Innovative). After this, sequestration soars to a peak around 2055, before declining. Implications of this are discussed in Section 4.4.

Box 1: Forestry carbon accounting

Carbon accounting for forestry is complex and multiple accounting methods exist. These different methods can lead to large differences in reported emissions in a particular year.

Table 2 compares the accounting method that Vivid used with the two currently-used accounting methods (GHG Inventory accounting and Kyoto accounting) and the method the Government intends to apply to New Zealand's 2030 target ("Modified Kyoto"). Vivid combined elements of the Modified Kyoto and GHG Inventory methods: they used an averaging approach for sequestration on forest land, but accounted for harvested wood products (HWPs) separately using real-time accounting and including HWPs from all forests (not just post-1989 forest land).

Vivid also averaged the total emissions over a 20-year period in the figures they presented for 2050. This is a sensible solution to problems associated with using a fixed harvest age in their model. That is an unrealistic assumption given the irregular age profile of New Zealand's forests and it leads to large variance in the year-on-year emissions estimates for HWPs. Using a 20-year average approximates a more realistic harvesting regime.

Due to the differences in accounting methods, caution is required in comparing the forestry emissions estimates in Vivid's report to values in the national greenhouse gas inventory. The same applies when comparing the results to New Zealand's 2030 target. The Government has not released detailed information on its intended accounting methodology, which makes any assessment in relation to the 2030 target difficult and uncertain.[25]

Further to the accounting method, another issue with the estimates is the parameters used in the carbon model. Of particular importance are the carbon yield tables, which estimate the carbon sequestered each year after a forest is planted. Vivid relied upon the Ministry for Primary Industries' default carbon tables for Emissions Trading Scheme participants. However, the Ministry for the Environment uses different tables in its national inventory

[25] Young, P. and G. Simmons. 2016. *Cook the Books*. Wellington: Morgan Foundation.

calculations which have significantly higher sequestration values.[26] This is another reason to be cautious comparing the results here and from Vivid's report with other sources.

TABLE 2: COMPARISON OF FORESTRY CARBON ACCOUNTING METHODS

	GHG Inventory accounting	**Kyoto accounting**	**NZ's proposed accounting method for 2030 target**	**Vivid's accounting method**
Base year	Includes emissions and sequestration from all forest land.	*1990 base year*: Post-1989 forest land (converted after 1989) treated as per GHG Inventory accounting. Pre-1990 forest land treated differently (see below).	1990 base year. (Distinction becomes irrelevant with averaging approach.)	
Harvest cycle	*Real-time emissions accounting*: Carbon model designed to track annual emissions and sequestration in real time.	Real-time accounting for post-1989 forest land. Pre-1990 forest effectively treated as steady-state, unless deforestation (i.e. land use change) occurs.[27]	*Averaging approach*: All forest land treated as steady-state once the "long-term average carbon stock" is reached (taking into account harvest rotation). No further emissions or sequestration is registered if land is replanted after harvest.	
Harvested wood products	Real-time accounting of all HWPs produced since 1900 (estimated).	Real-time accounting for HWPs produced from post-1989 land. HWPs from pre-1990 land treated as steady-state.	Included in calculation of long-term average carbon stock.[28]	Same as GHG Inventory accounting (includes HWPs from all forest land).

[26] These are not published, but the Ministry provided them to me on request for a previous project.
[27] More correctly, pre-1990 forest is accounted for relative to a business-as-usual "forest management reference level". Changes relative to this reference level due to changed management practices (such as change in harvest rotation) could be credited or debited. See Vivid Economics (2017b), p. 65.
[28] This is my interpretation of the description of the accounting methodology in New Zaland's Nationally Determined Contribution (emphasis added): "*Forests established after the base year will continue to be accounted for as they would under the Kyoto Protocol, but once they attain their long-term average carbon stock, **taking into account all carbon pools and activities**, the forest will transfer to the Forest management/Forest remaining forest category, where it will be accounted for under a business-as-usual reference level.*"

4.2 GROSS AND NET EMISSIONS PATHS

Combining all the sectoral emissions paths produces the total gross and net emissions paths shown below in Figure 12. The results are also presented in Table 3.

FIGURE 12: INDICATIVE GROSS AND NET EMISSIONS PATHS

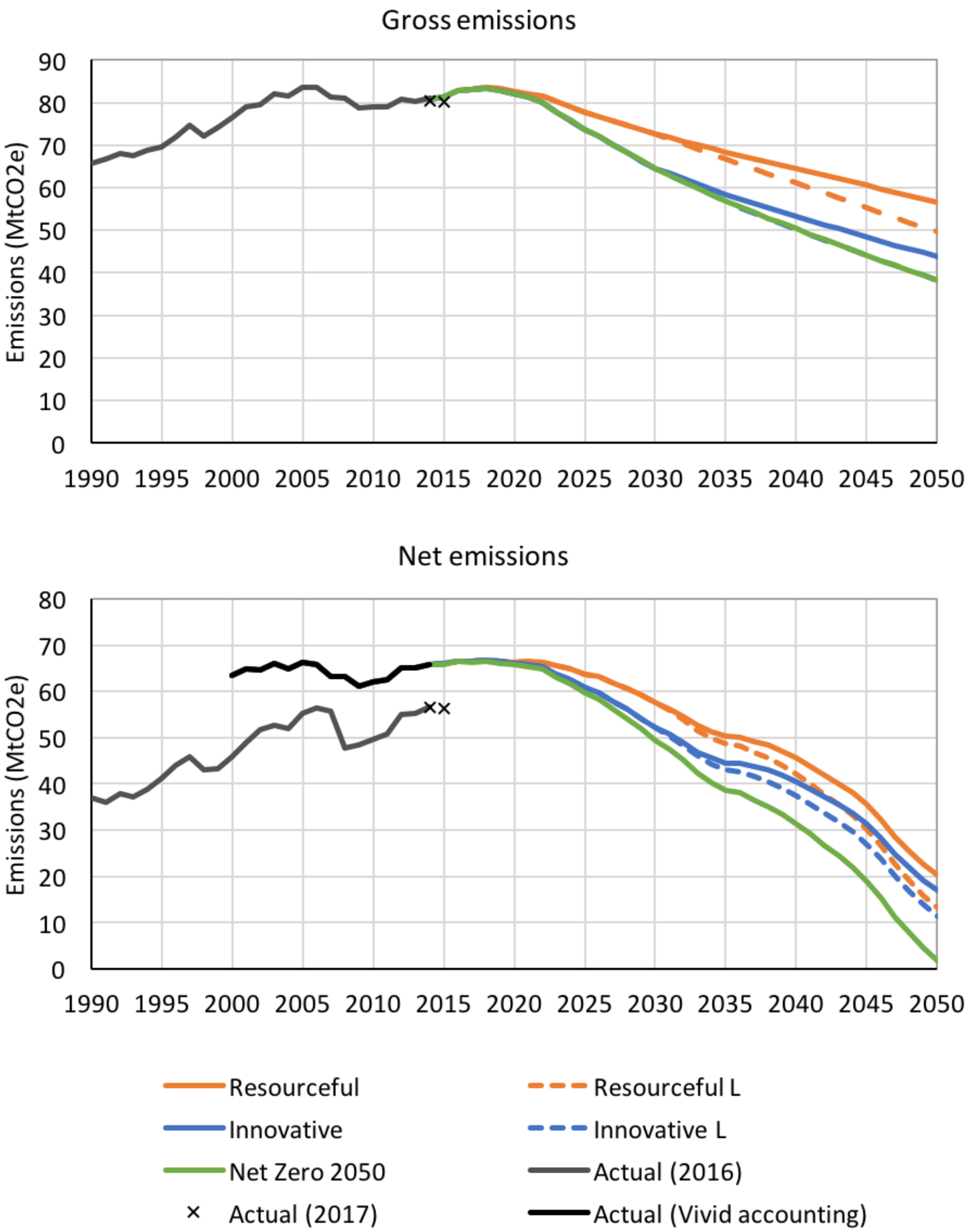


TABLE 3: TOTAL GROSS AND NET EMISSIONS PATHS

		2014	2020	2025	2030	2035	2040	2045	2050	*Change 2014-2030*	*Change 2014-2050*
		Annual emissions (MtCO2e)									
Gross emissions	*Resourceful*	81.1	82.6	77.7	72.6	68.4	64.5	60.7	56.6	-10%	-30%
	Innovative	81.1	82.1	73.7	64.5	58.3	53.3	48.5	43.8	-20%	-46%
	Net Zero 2050	81.1	82.2	73.7	64.6	56.8	50.3	44.2	38.3	-20%	-53%
Net emissions	*Resourceful*	65.8	66.2	63.7	57.5	50.3	45.5	35.5	20.2	-13%	-69%
	Innovative	65.8	66.1	60.9	52.1	44.5	40.4	31.3	16.9	-21%	-74%
	Net Zero 2050	65.8	65.8	59.8	49.5	38.7	31.3	18.9	1.8	-25%	-97%

Note: All net emissions values here are calculated using Vivid's forestry accounting method. Because of this, the 2014 value differs from the national inventory value, and the percentage reductions by 2050 differ from values presented in Vivid's report.

TABLE 4: CUMULATIVE EMISSIONS UNDER THE EMISSIONS PATHS

		2016 – 2020	2021 – 2025	2026 – 2030	2031 – 2035	2036 – 2040	2041 – 2045	2046 – 2050	*First Paris period (2021 – 2030)*	*Total (2016-2050)*
		Cumulative GHG emissions (all gases, MtCO2e)								
Gross emissions	*Resourceful*	415	401	373	350	330	311	291	774	2,471
	Innovative	414	388	341	304	276	252	228	729	2,204
	Net Zero 2050	414	388	341	300	264	233	203	730	2,144
Forestry	*Resourceful*	-83	-74	-71	-86	-90	-111	-162	-145	-677
	Innovative	-82	-70	-61	-68	-63	-75	-117	-131	-536
	Net Zero 2050	-83	-74	-71	-86	-90	-112	-162	-145	-679
Net emissions	*Resourceful*	332	327	302	265	240	199	129	629	1,794
	Innovative	332	318	280	237	213	177	111	598	1,668
	Net Zero 2050	331	314	270	214	174	121	41	584	1,465

In the net emissions graph, the calculated values differ from the national inventory values because of the different forestry accounting methods used (see Section 4.1.5 and Box 1 on p. 27). As discussed earlier, this means we need to be careful comparing these results with other sources.

The emissions paths see both gross and net emissions peaking in 2018. On gross emissions, all scenarios achieve their fastest rate of reduction through the 2020s, with progress gradually slowing after that. The rate of reduction is roughly twice as fast in Innovative and Net Zero 2050 compared with Resourceful. Relative to 2014, the paths see gross emissions reduced 10-20 per cent by 2030 and 30–53 per cent by 2050.

The surge in net forestry sequestration beginning in 2035 compensates for the slowdown in progress on gross emissions, and drives very rapid reductions in net emissions towards the middle of the century. Relative to 2014, net emissions are 13-25 per cent lower by 2030 and 69–97 per cent lower by 2050. Net Zero 2050 comes extremely close but falls just short of fulfilling its name.

While the Paris Agreement text does not make this distinction, the key condition for stabilising global temperatures is for emissions of long-lived greenhouse gases (primarily carbon dioxide and nitrous oxide) to reach net zero.[29] The scenarios all achieve this milestone between 2045 and 2050.

Table 4 shows the cumulative emissions for all gases in five year periods from 2016. Over the whole time period from 2016–2050, cumulative gross emissions span a range of 2,144–2,471 $MtCO_2e$. Cumulative net emissions range from 1,465–1,794 $MtCO_2e$.

4.3 ANALYSIS WITH RESPECT TO NEW ZEALAND'S 2030 TARGET

Under the Paris Agreement, New Zealand has set a 2030 emissions target of 30 per cent below the 2005 gross emissions level. The target applies to net emissions using the proposed "Modified Kyoto" forestry accounting method described in Box 1 (p. 27). For compliance, the target will be converted into a 2021–2030 "carbon budget".

The Ministry for the Environment currently estimates a provisional carbon budget of 594 $MtCO_2e$ and forecast gross emissions of 814 $MtCO_2e$ over the period.[30] These values are based on the 2017 national inventory, which makes them slightly inconsistent with our data.[31] Ignoring this and comparing the numbers in Table 4 at face value implies a gross emissions abatement of 40–85 $MtCO_2e$ in these emissions paths beyond what current policies are expected to deliver.

[29] Short-lived gases, of which methane is by far the most important, are not required to go to zero, as an ongoing steady flow leads to a stable atmospheric concentration. However, deep, sustained reductions in methane will still be required to meet the goals of the Paris Agreement.
[30] http://www.mfe.govt.nz/climate-change/nz-ets-and-nzs-carbon-budget-in-the-2020s
[31] The previous carbon budget estimate (based on the 2016 inventory) was 611 Mt. For simplicity, I stick with the current estimates.

Taking the net emissions numbers at face value, it appears that the Net Zero 2050 path comes in under the 2021–30 carbon budget (at 584 MtCO2e), and the other scenario paths are not far above it. However, as discussed in Box 1, this direct comparison is problematic because the forestry accounting method used by Vivid does not fully align with the Government's proposed method – particularly on the treatment of HWPs.

As a sensitivity test, if we were to exclude HWPs altogether and look only at *in situ* forest carbon, the net sequestration over the period would be 43–53 MtCO_2e. This constitutes an extreme lower-bound sequestration estimate. Using these values, net emissions over the period would range from 677–721 MtCO_2e.

Due to the significant uncertainties around the sequestration estimates, the above figures should be interpreted and used with due caution.

4.4 BEYOND 2050: GETTING TO AND SUSTAINING NET ZERO EMISSIONS

In the *Net Zero in New Zealand* summary report, Vivid states that the Innovative and Resourceful scenarios would both "place the economy on a path to net zero emissions before 2100". However, there is an important caveat summarised in their fifth key conclusion:

> *"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."*

They elaborate on this point in the executive summary:

> *"**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."*

To explore this matter, and the question of if and when net zero might be achieved, I extended all of the emission paths out to 2070. This involved extending the trajectories for all of the drivers described in Chapter 3 (listed in Table 5). I did this by:

- For forestry, maintaining Vivid's specified planting schedule (i.e. declining to zero from 2050 to 2070);
- For those drivers using a particular equation or model (e.g. vehicle electrification, dairy cow population), maintaining and extending this;
- In all other cases, linear extrapolation based on the trend over the decade to 2050.

In general, this assumes further incremental progress, and only in the areas where changes are already occurring. There is no acceleration of effort and no new mitigation options beyond those Vivid included.

The results are shown in Figure 14. The key observation is that under these extended assumptions, neither Resourceful nor Innovative would in fact ever reach net zero emissions. Particularly in Innovative, many current emissions sources (such as light vehicles and low-grade heat) are almost completely decarbonised by mid-century so cannot yield meaningful further reductions. Due to the combined effect of slowing reductions in gross emissions and declining sequestration from forestry, net emissions begin to rise again after around 2060. The low industry scenario variations of Resourceful and Innovative (not shown here) do not reach net zero emissions either; Net Zero 2050 is the only scenario that does. But even Net Zero 2050, without new or accelerated mitigation actions or new ways of sequestering CO_2, would only achieve this goal temporarily; net emissions rise back above zero before 2070.

This serves to illustrate Vivid's points above. To reach and then sustain net zero emissions, it will be necessary to take additional mitigation actions beyond those included in these scenarios. For Resourceful, that would likely mean belated adoption of the additional energy technologies (such as electrification of high-grade heat), or alternatives to these, in the post-2050 period. That is, the additional forest planting only delays but does not avoid the need for other changes in the economy. Furthermore, from a cumulative emissions perspective, land can always be afforested later and will lock up the same amount of carbon over time, whereas delayed reductions in gross emissions (particularly of long-lived gases) cannot simply be reversed.

FIGURE 13: NET EMISSIONS PATH TO 2070

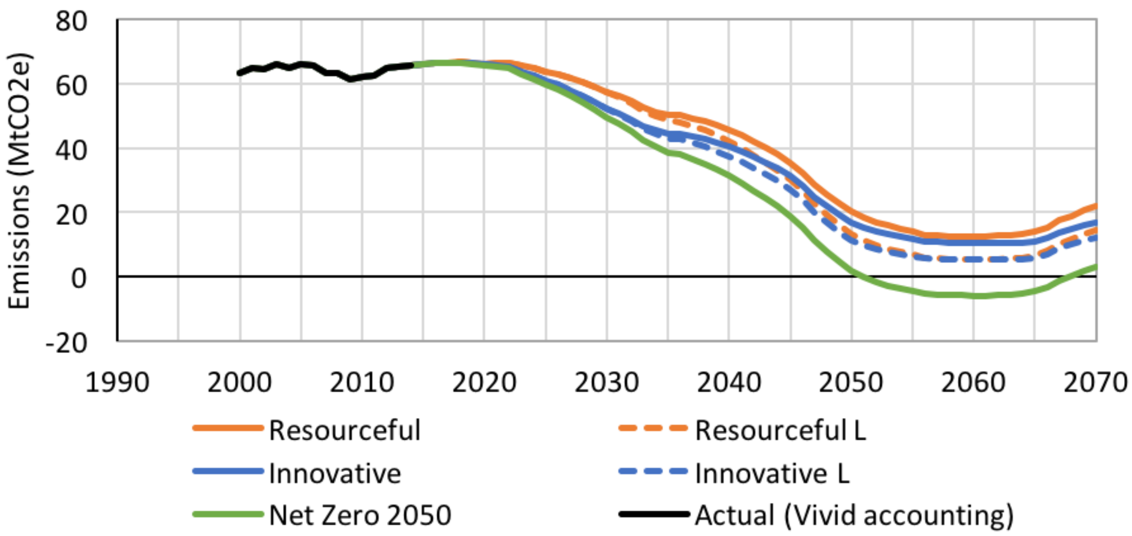
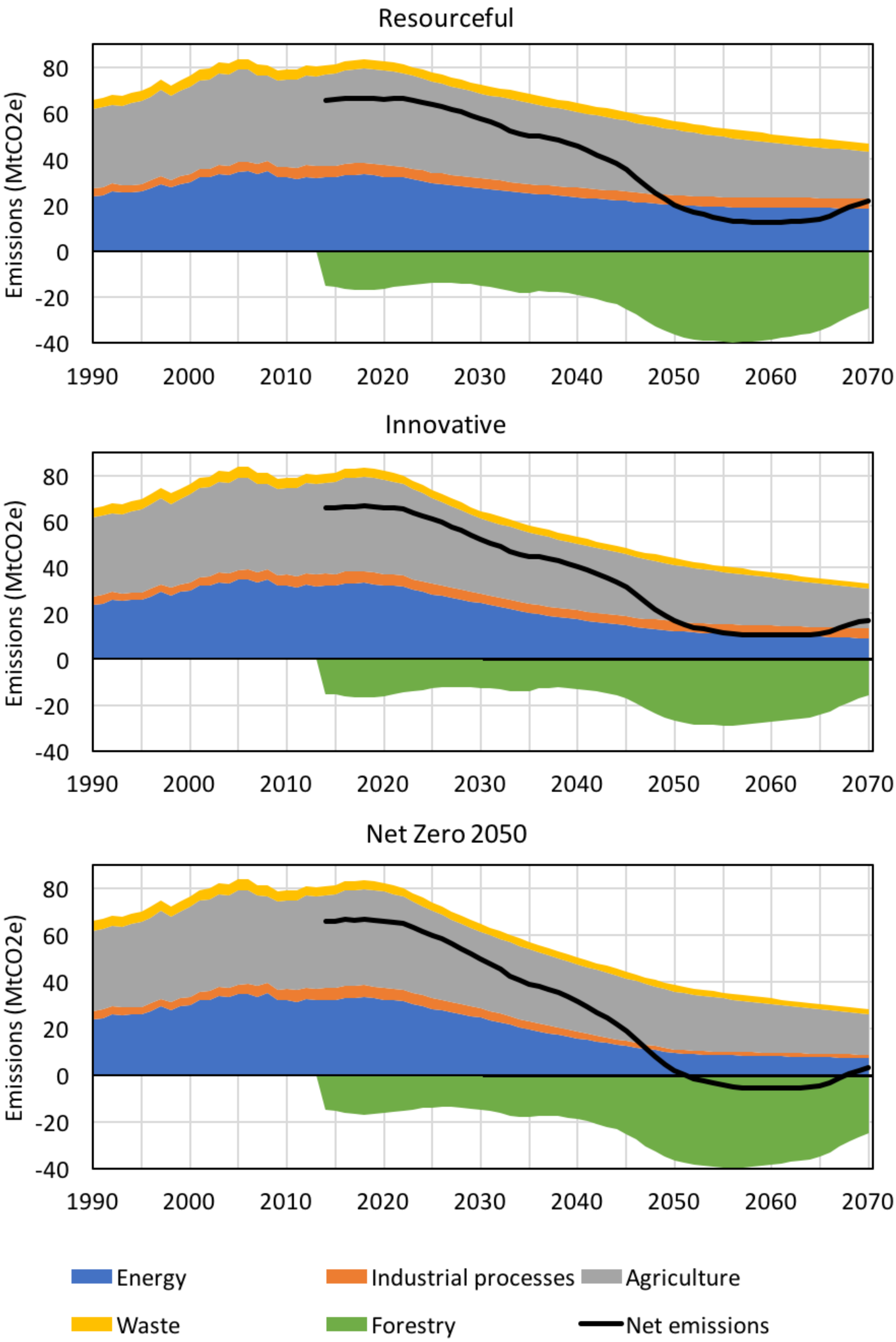


FIGURE 14: EMISSIONS BY SECTOR TO 2070



5 DISCUSSION AND RECOMMENDATIONS

This paper builds on the work of Vivid Economics by exploring transition paths consistent with scenarios in the *Net Zero in New Zealand* report. Using a backcasting approach, I have sought to create realistic paths between now and 2050. I have also extended the paths further, out to 2070. Together, these form a broad-banded indicative pathway towards domestic emissions neutrality, which GLOBE-NZ could use for the basis of further conversation and analysis.

This indicative pathway serves as a sound and consistent starting point, but does not span the full range of possibilities for how the transition could occur. The scope of this project limited the extent of analysis on the trajectories of the various drivers of emissions. Across all areas, there is potential for accelerated or delayed action, while arriving at the same point in 2050. This could warrant further exploration, particularly in areas such as light vehicle transport that could be subject to disruptive change. Simplified assumptions were necessary in several cases: where the evidence base is poor, such as for electrification of heat; and where the timing is highly uncertain, such as for industry closure and adoption of a methane vaccine.

Through the course of this project, it has become evident that there are issues around Vivid's forestry sequestration estimates which need to be resolved. Differences between the accounting method used in the report and the methods used by the New Zealand Government make comparisons difficult, leading to potential for confusion. Variations in forest carbon model parameters may also lead to significantly different outcomes. I therefore recommend that the forestry sequestration estimates be reviewed, ideally with input from relevant government departments. Such a review could also look at alternative planting scenarios developed by Mason & Morgenroth.[32] In the meantime, the forestry emissions and net emissions results in this paper should be viewed as tentative.

Recommendation 1: Forestry sequestration estimates should be reviewed.

While the main focus of this report is on the emissions path, as discussed in Section 1.3, this is one of a range of components that may make up a "2050 pathway". Other potential components on which this paper offers some insight are indicators and milestones. An example indicator would be electric vehicle market share, with corresponding milestones based on backcasting from a 2050 fleet electrification target. The simple analysis undertaken for this paper suggests that the Innovative scenario would require electric market share for light vehicles to reach 50% by around 2025 and 100% by around 2035. Defining a pathway using tangible measures such as this, in addition to emissions levels, may help with policy development and with determining progress. I recommend that GLOBE-NZ consider broader elements such as these as part of its pathways conversation. There is an opportunity to participate in and help shape the global conversation in this area through the 2050 Pathways Platform, which the New Zealand Government has signed up to.

[32] Mason, E. G. and J. Morgenroth. 2017. Potential for forestry on highly erodible land in New Zealand. *NZ Journal of Forestry*, May 2017, Vol. 62, No. 1.

Recommendation 2: Consider additional elements beyond emissions levels in defining a pathway to domestic emissions neutrality.

This paper also extends the scenario analysis beyond 2050, which highlights serious challenges in getting to and sustaining net zero emissions. Obviously, there is limited value in attempting to look too far into the future. However, this warrants a closer look at some areas of the economy where further emissions reductions may be possible – in particular, those emissions sources that do not reduce (and in some cases actually grow) under Vivid's scenarios. These include: air, sea and rail transport; fugitive emissions from natural gas production and geothermal; cement and lime production; horticulture; and wastewater. In some cases, driver assumptions used by Vivid appear conservative – for example, the relatively slow freight efficiency gains,[33] lack of further electrification of rail, and growth in fugitive emissions from natural gas. In other areas, such as air travel and cement production, structural changes such as demand reduction and product substitution have not been explored but could play an important role.[34]

Recommendation 3: Continue to consider and explore emissions reduction opportunities going beyond those featured in Vivid's scenarios.

One way to enable further exploration of the range of choices available, and uncertainty around how the various drivers of emissions might change, would be to develop an interactive calculator tool. The UK Government's 2050 Calculator[35] provides a template which has been adopted by 24 other countries, regions and cities,[36] including Wellington.[37] The calculator developed by Vivid Economics is somewhat different but has a similar underlying logic and structure, and could be quite readily adapted.

Recommendation 4: Explore the potential for interactive tools to assist in further development and communication of a pathway to domestic emissions neutrality.

[33] http://morganfoundation.org.nz/electrifying-getting-zero-carbon-transport-new-zealand/

[34] For example, in Australia, think-tank Beyond Zero Emissions has produced a report on pathways to zero carbon cement, and company Mineral Carbonation International aims to be producing negative-emissions "green concrete" at a commercial scale by 2020.

[35] http://2050-calculator-tool.decc.gov.uk/

[36] https://www.2050.org.uk/

[37] http://www.climatecalculator.org.nz/

APPENDIX 1: LIST OF KEY DRIVERS AND ASSUMPTIONS

TABLE 5: LIST OF KEY DRIVERS FOR EACH SECTOR WITH ASSUMPTIONS USED BY VIVID

ELECTRICITY	Resourceful	Innovative, Net Zero 2050
Electricity demand	46% baseline growth in electricity consumption between 2014 and 2050 (following EDGS Mixed Renewables scenario). Further demand growth from electrification of transport and heat, and reductions due to efficiency and industry closures, are calculated based on scenario assumptions in other sectors.	
Energy efficiency	No improvement beyond baseline.	Additional 0.1% per annum improvement beyond baseline.
Generation mix	91% renewable in 2050 (8% gas, 1% coal; 22% geothermal, remainder from non-emitting sources). Based on EDGS Global Low Carbon scenario.	98% renewable in 2050 (2% gas, 0% coal, 20% geothermal, remainder from non-emitting sources).
Geothermal fugitive emissions intensity	No change.	Improvement rate of 1.4% per annum (39% decrease by 2050).
TRANSPORT	**Resourceful**	**Innovative, Net Zero 2050**
Light vehicle travel demand	10% reduction in VKT per capita from 2014 level by 2050.	
Light vehicle fuel efficiency	Improvement rate of 1.8% per annum (90% by 2050).	Improvement rate of 1.9% per annum (97% by 2050).
Light vehicle electrification	85% of light vehicle travel by 2050	95% of light vehicle travel by 2050
Freight demand	Growth rate of 1.54% per annum for land and sea freight (73% by 2050).	
Freight mode shift	Rail share of land freight increases from 12% in 2014 to 15% in 2050.	Rail share increases to 25% in 2050.
Road, rail and sea freight efficiency	Improvement rate of 0.3% per annum (11% by 2050).	Improvement rate of 0.4% per annum (15% by 2050).
Heavy vehicle electrification	25% by 2050.	50% by 2050.
Rail electrification	Unchanged at 21%.	
Domestic air travel demand	Growth rate of 3.2% per annum (211% by 2050).	
Air travel efficiency	Improvement rate of 3.0% per annum (190% by 2050).	Improvement rate of 3.1% per annum (200% by 2050).
OTHER FOSSIL FUELS	**Resourceful**	**Innovative, Net Zero 2050**
Energy demand	Demand for dairy farming and processing, pulp, paper and wood processing is calculated from activity levels based on assumptions in other sectors. All other sub-sectors use baseline growth rates for electrical and non-electrical energy demand from EDGS Mixed Renewable scenario. Demand from petroleum, chemicals and primary metals manufacturing linked to levels of industry activity.	
Energy efficiency	Improvement rate of 1% per annum in pulp, paper and dairy (43% by 2050).	Additional 0.1% annual improvement beyond Resourceful in all sub-sectors.
Electrification level	By 2050: increase in low-grade heat (to 75%), and medium-grade heat (to 13%).	Increase in low-grade heat (to 95%), medium-grade heat (to 19%), high-grade heat (to 34%) and mobile motive power (to 25%).

Bioenergy substitution	All medium-grade heat in pulp, paper and wood. 75% of medium-grade heat in agricultural processing.	
FUGITIVE EMISSIONS	**Resourceful**	**Innovative, Net Zero 2050**
Geothermal energy use	Calculated from electricity generation and assuming geothermal heat use grows in proportion to total non-electrical energy demand (4% by 2050).	
Geothermal emissions intensity	No change.	Improvement rate of 1.4% per annum (reduction of 39% from 2014-2050).
Emissions from oil refining and coal mining	Scaled with levels of industry activity (petroleum and chemicals; iron and steel production).	
Emissions from natural gas production	Scaled with baseline non-electric energy demand (4% growth to 2050).	
INDUSTRIAL PROCESSES AND PRODUCT USE	**Resourceful**	**Innovative, Net Zero 2050**
Level of industrial activity	Mineral production scaled with population (35.4% growth from 2014 to 2050). Chemical and metal production scaled with baseline non-electrical energy demand (4% growth to 2050)	
Industry closure	Chemical and metal industries closed in Net Zero 2050 and in "low industry sensitivity" variations for Resourceful and Innovative.	
Process efficiency	No improvement.	Improvement rate of 0.1% per annum (4% by 2050).
Use of HFCs	Reduction of 85% from 2014 to 2050.	
AGRICULTURE	**Resourceful**	**Innovative, Net Zero 2050**
Livestock numbers	From 2014 to 2050: 10% reduction in dairy cows, 20% reduction in beef cows, 25% reduction in sheep.	20% reduction in dairy cows, 30% reduction in beef cows, 35% reduction in sheep.
Stocking rate	Increase of 10% for all types of livestock.	Decrease of 20% for dairy. Increase of 10% for sheep and beef.
Production per animal	Increase of 15% for all types of livestock.	Increase of 25% for dairy, 15% for sheep and beef.
Baseline emissions intensity	10% reduction for all types of livestock.	
Enteric fermentation		
Breeding	15% reduction in emissions intensity (beyond baseline). 100% adoption.	
Feed	10% reduction in emissions intensity. Adoption rate of 70% for dairy, 10% for beef, 0% for sheep.	
Methane vaccine or inhibitor	20% reduction in emissions intensity. Adoption rate of 80% for dairy, 0% for sheep and beef. (No vaccine.)	For dairy, 30% reduction in emissions intensity with 100% adoption. For sheep and beef, 20% reduction in emissions intensity with 90% uptake.
Animal waste and fertiliser		
Accelerated efficiency and precision agriculture	10% reduction in emissions intensity. Adoption rate of 100% for dairy, 30% for sheep and beef.	
Feed (low nitrogen)	10% reduction in emissions intensity. Adoption rate of 70% for dairy, 10% for beef, 0% for sheep.	
DCD (nitrification inhibitor)	20% reduction in emissions intensity. Adoption rate of 40% for dairy, 0% for sheep and beef.	
WASTE	**Resourceful**	**Innovative, Net Zero 2050**
Population	Median projection from Statistics NZ (35.4% growth 2014 to 2050)	
Waste quantity		

Municipal solid waste	25% reduction per capita by 2050.	50% reduction per capita.
Construction & demolition waste	Constant amount per capita, but 25% diverted from landfill by 2050.	
Wastewater	Constant amount per capita	
Unmanaged sites	10% reduction in total waste.	20% reduction in total waste.
Emissions intensity / methane capture	25% decrease for municipal solid waste only.	50% decrease for municipal solid waste. 20% decrease for farm waste.
FORESTRY	**Resourceful, Net Zero 2050**	**Innovative**
New exotic plantings	Total of 1.6 million ha to 2050, 2.1 million ha to 2100.	Total of 1.1 million ha to 2050, 1.5 million ha to 2100.
New native regeneration	Total of 1.0 million ha to 2100.	Total of 0.5 million ha to 2100.
Time profile of planting	Linear increase from 2015 to 2030; constant to 2050; linear decrease to zero in 2070.	
End uses (mix of harvested wood products)	By 2050: 150% increase in hardwood; 55% increase in biofuels; 0% increase in paper. Surplus wood exported as raw logs.	By 2050: 100% increase in hardwood; 34% increase in biofuels; 0% increase in paper. Surplus wood exported as raw logs
Deforestation	Zero (all forest land remains in its current use).	