Farms, forests and fossil fuels: The next great landscape transformation?

March 2019

Parliamentary Commissioner for the Environment
Te Kaitiaki Taiao a Te Whare Pāremata

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Overview for policymakers

This is a report about a different approach to framing New Zealand's long-term climate change targets and policies and what that could mean for our landscapes. It is, in particular, about how we might deal with our agricultural greenhouse gases and our forest sinks in a joined up way and deal with fossil carbon dioxide emissions separately.

Parliament is about to debate legislation that will set down a long-term emissions reduction target for New Zealand. Long term in this case means 2050. That would require agreeing to a target that can outlast the parliamentary careers of almost anyone currently elected to the House of Representatives. The framework that is established will cast a long shadow.

Meeting our long-term targets will require policies and innovations that have yet to be crafted. This is especially true for biological emissions from agriculture, which are to be addressed for the first time. Aotearoa New Zealand's landscapes have endured two centuries of upheaval. How we frame our targets with respect to biological sources and sinks will write the next chapter of landscape transformation.

My advice to Parliament last year was that advising on our long-term target should be the new Climate Commission's first task. It remains my advice. But the commission hasn't yet been established. So I have decided to provide some thoughts on the matter myself.

A declaration of interest - and responsibility

It might be appropriate to commence this overview with a declaration of interest. I am a heavy user of fossil fuel – like most New Zealanders, principally as a mobile citizen. I use planes and cars. I live on the farm on which I was born. My family has interests in farming and forestry. So I am part of both the fossil and the biological economies. Again, I share that with many New Zealanders. This report is not written in the abstract. It deals with the lives of all of us.

But in my case it doesn't stop there. I also have some responsibility for the way climate policy has evolved. At the national level I spent the 1990s as a Minister trying to understand what responding to first the United Nations Framework Convention on Climate Change and then the Kyoto Protocol meant for domestic climate policy in New Zealand.

I investigated taxes and emissions trading schemes. And I oversaw the development of a negotiating position that gave countries like New Zealand maximum flexibility in being able to treat all sources and sinks as essentially substitutable using a common metric. The basis of that approach could be summed up like this:

"It's the net contribution to the atmosphere of greenhouse gases that counts whatever the sources or sinks. In the interests of minimising the cost of reducing emissions, any mix of actions will suffice as long as the quantum of gases – adjusted for their radiative warming potential minus sinks – takes us on a downwards path."[1]

Coming up with a common metric was necessary to enable countries to compare their efforts in a standardised format. But in New Zealand's case it was also a matter of pursuing a mitigation policy at the least possible cost. And for New Zealand, forests provided the key low-cost pathway forwards. In the early 1990s, when we had large, new, rapidly growing plantation forests, we were very happy to count the carbon sequestration they represented into the equation. In fact, New Zealand's very first domestic target was developed on the basis that we would rely 20 per cent on emissions reductions and 80 per cent on forest sinks to meet it.

The approach was not without its critics. I recently dug out an address I gave 25 years ago in which I replied to one critic, Greenpeace, by saying: "Scientifically, it is incontrovertible that an atom of carbon locked up (sequestered) is as good as an atom of carbon not emitted into the atmosphere."

I may have then qualified that by saying: "No one is arguing that sinks are the whole answer. Sinks won't last indefinitely – our credit is likely to run out by around 2020." But I don't mind admitting that the sheer scale of forest sinks at the time (and the eternity that a date 16 years away represents when you're only 36) made offsetting a very attractive policy response.

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[1]Upton, 2018.

When challenged by the obvious criticism that we risked covering the country in trees and leaving fossil emissions untouched, I argued that they were a bridge to a low emissions future; that forest sinks represented a relatively low-cost approach while we waited for new technologies to be developed. As a country with some emissions that appeared very difficult to reduce – notably those from agriculture – it seemed a reasonable way forward.

But my responsibility doesn't stop there. Because about ten years ago, in the wake of the unsuccessful Copenhagen climate summit, I started to try to engage a global debate on the end-point to which climate change targets and policies should be directed. That led, in 2013, to a lecture I prepared that was delivered by the Secretary-General of the Organisation for Economic Co-operation and Development, in which he called for "the complete elimination of emissions to the atmosphere from the combustion of fossil fuels in the second half of the century".[2]

It was the first time a major world leader had made the link between what had been clear from climate science for at least 20 years and the need for a time frame in which policies would have to bite if the rise in global average temperatures were to be limited to no more than an increase of two degrees Celsius.

I remain as persuaded as I ever have been of the serious risk that human-induced climatic disruption poses, and the need for decisive action. What was a long-term risk management challenge has in the meantime become increasingly urgent as policy ambitions have fallen short of what is required. I bear my share of responsibility for that.

What has changed?

The Paris Agreement of 2015 changed the nature of the debate in two ways. It acknowledged for the first time the scientific reality that economies would need to decisively wean themselves from reliance on fossil fuels and within a time frame of only a few decades. Secondly, it gave up on the almost utopian quest for a globally determined, top-down allocation of national emissions quotas. Rather, it was left to nations to say how they would contribute to achieving a "balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century".[3]

It is this 'bottom-up' approach that jolted me to think about the differences between the gases that make up New Zealand's contribution to global warming, the integrity of forest sinks as an offset for fossil carbon dioxide emissions and the need to make progress across all gases within roughly five decades.

To date, the debate in New Zealand has always commenced from the same premises: that all greenhouse gas sources and sinks are fully substitutable, one for another;

[2] Gurria, 2013.

[3] Paris Agreement, Article 4.1, December 2015.

and that we must find the least-cost way of effecting the economic transition that emissions reduction targets require.

Putting the two propositions together generates a rather narrow landing space for policies – some sort of flexible pricing mechanism thereby incentivising an exploration for the least costly technological or management innovations wherever they may be found. If we can just generate the right emissions price, the market will do the rest.

That is certainly one way to tackle the problem. It has an elegance and simplicity that cuts through the complexity of a modern economy and limits the space for lobbying. And in our Emissions Trading Scheme (NZ ETS) we have the architecture for such an approach. The fact that we don't yet have an economy-wide price is often explained as a lack of political will – a reminder that whatever its market credentials, an emissions trading scheme is a creature of politics.

That is not a reason to reject it. But we should at least be open to the possibility that the underlying premises we have long taken for granted may not be unassailable, in particular the claim that all greenhouse gas sources and sinks are fully substitutable.

In many countries, where the combustion of fossil fuels provides the overwhelming majority of emissions, this is probably a subject of marginal interest. But in New Zealand's case, where a high share of our emissions come from biological sources and forests are perceived to be a lifeline in providing low-cost mitigation, it is a premise that deserves careful attention. It is one with which I used to be entirely comfortable. That is no longer the case.

I have come to the conclusion that our current premise is questionable. It attempts to condense the many different physical characteristics of the gases we produce into a single variable. Glossing over these physical differences becomes risky for countries with emissions profiles like New Zealand. While it would be nice if we could read a solution from the science, we can't. The planetary biogeochemical cycles we are interfering with are vastly complex and there will be plenty of surprises to come. But we do know that the gases aren't all the same.

While the way the current framework accounts for each gas may be convenient and serviceable, it isn't necessarily a sensible basis for long-lasting climate mitigation. It is for this reason that, in my view, New Zealand would be well advised to treat fossil and biological sources and sinks separately. That has implications for the way we define our long-term target and the policies we might pursue to reach it.

On the premise that targets and policies have to be achieved at the least practicable cost, I have fewer misgivings. Climate policies will impose costs. They will only be tolerated if the wider community considers them reasonable. So thinking about cost will always have to be front-of-mind.

The challenge, rather, is to understand what costs we are talking about, on whom they will be imposed and over what time frames. What are the risks that different strategies run? The greenhouse gases we are seeking to constrain are responsible for more than just global warming. They affect other environmental challenges from the ozone layer to ocean acidification. Similarly, the trees we might plant to mitigate warming supply other environmental benefits as well. But because they have, in effect, to be maintained forever, we have to understand something about the options we are closing off.

The long-term consequences of different approaches to managing our greenhouse gases has led this report to focus less narrowly on warming, and rather more on what sort of transformation of our landscape we could be letting ourselves in for. The scale of the climate challenge is such that, should we meet it, the shape and structure of our economy will look very different regardless of the path we choose. That will be true of every society. Equally, if we fail to rise to the challenge, our economy and environment will also be transformed but in a much less pleasant way.

In New Zealand's case, given the biological nature of our economy, the way we respond to climate change will have physical, environmental, visual, cultural and social consequences that will be much more apparent than they might be in a more purely industrial or service-based economy. Climate is just one of a number of stressors that plague our landscapes. Water pollution, soil depletion, biodiversity loss and pest invasions are just some of the problems we are grappling with – and all of which climate change will exacerbate.

In addressing emissions reductions, we have to be aware of the knock-on consequences for these other environmental challenges. We also have to be aware of the families and communities, the whānau and the hapū who actually live in the places where we emit half our biological gases (methane and nitrous oxide) and contemplate storing our carbon waste. We need more than an accounting approach for our climate targets, and policy responses that better reflect the physical science and the risks we are willing to run.

The argument of the report

This is a lengthy report. A summary of the argument follows. In addition to describing a different approach to framing targets and policies, the full report compiles the results of a large amount of research. As such, chapters one to three are a compendium of research that can be referred back to if detailed explanations are called for. Readers wishing to explore the key policy-relevant findings should turn to chapters four to six.

Chapter one sets the scene by placing current decisions about climate policy in the context of New Zealand's history and development. From the very first moment of settlement – more recent here than anywhere else in world – humans have set about transforming the landscape in ways that have been unintended as often as they have been intended. In the process, we have profoundly changed the operation of the natural carbon cycle.

New Zealand's biggest contribution to global climate change so far has come from the vast quantity of carbon we have shifted from the land – its forests and soils – to the atmosphere. This still exceeds the volume of carbon dioxide we have emitted from the combustion of fossil fuels.

New Zealand has undergone a series of landscape transformations. At first there was deforestation driven by the needs of Polynesian and European settlers. Then, as New Zealand became connected to a global marketplace, changes to our landscapes started to be driven by consumers on the other side of the planet.

Further deforestation in pursuit of a pastoral economy became the driver. Reforestation was driven by the development of a plantation forest industry. Subsidies introduced to support agriculture ended up seriously distorting land use. Their removal led to another convulsion in our landscapes, followed by a new phase of intensification and diversification that continues to this day.

In short, New Zealand has witnessed a series of dramatic changes in land cover and land use, each of which has moved round large amounts of carbon. The way in which we go about responding to climate change will once again drive land use change and the way in which we intervene in the carbon cycle.

Chapters two and three seek to provide the reader with an up-to-date account of how science understands human activities to be changing the planet and how those activities have played out in New Zealand.

Chapter two describes the different physical characteristics of the three main gases contributing to anthropogenic global warming – carbon dioxide, methane and nitrous oxide. It describes the different biogeochemical cycles that shift carbon and nitrogen around the planet. I have described these in some detail to provide a resource for those interested in the complexities – of which there are many – and to support the conclusions that the report draws about the wisdom of simply regarding all sources and sinks as substitutable one for the other.

To understand their ongoing impact and any practical policy responses that may be available, it is necessary to consider how these gases come to be produced or co-produced and how their impacts relate to one another.

With the science described, **chapter three** describes the contribution carbon dioxide, methane and nitrous oxide have made to New Zealand's emissions profile over the last 200 years. It charts the course of two centuries of nearly constant land use change as different commodity booms and busts have shaped New Zealand's landscape.

While most attention is currently directed to agricultural greenhouse gases, land use change emerges as New Zealand's biggest contribution to global warming. More than 3 billion tonnes of carbon have been shifted to the atmosphere from the land, largely as the result of forest clearance to make way for agriculture. The approximate scale of warming associated with these changes is estimated to be around seven times larger than our contribution of fossil emissions.

Responding to climate change – and addressing a wide range of other environmental pressures – is causing New Zealanders to consider the way land is used and managed. One option is store more carbon on the land in trees. While there is no shortage of available land for reforestation, the way and the extent to which it is done will need careful consideration.

While forests can be long-lived, they cannot be regarded as permanent. Their increasing exposure to climate change impacts through fire, pests, pathogens and erosion, further underscores their impermanence. Given these risks and the uncertainty that attaches to their temperature benefits, heavy reliance on forest offsets comes with risks.

Chapter four broaches the core proposition that this report questions: should we, in setting emissions reduction targets and designing climate change mitigation policies, continue to regard all anthropogenic sources and sinks as fully substitutable for one another?

This current approach implies that it does not matter which gas is focused on as long as you have a handy means of equating the different lifetimes and potencies of the gases. The same logic underpins the premise that carbon sequestered and locked up in trees can fully offset the impact of carbon dioxide, methane or nitrous oxide emissions from any source.

While this may be appropriate for accounting purposes, the real-world differences between the main greenhouse gases suggest that the risks they pose aren't all the same. Two main problems with the current approach are identified:

- First, a single target that includes all sources and sinks renders the temperature outcomes of climate policies uncertain. If no specific target is set for gross fossil carbon dioxide emissions, emissions reductions of methane or nitrous oxide could be substituted for action on reducing fossil carbon dioxide. However, different combinations of reductions will not lead to the same temperature outcomes.
- Second, the fossil carbon dioxide emitted into the atmosphere has a warming effect for centuries to millennia. By contrast, the carbon stored by trees and other terrestrial ecosystems can be quickly released back into the atmosphere in the event of fires, pests or other disturbances. Continuing to emit fossil carbon dioxide on the basis that an equivalent amount of carbon is being sequestered by biological sinks therefore carries significant risks.

Furthermore, the extremely long-lived warming impact of carbon dioxide from fossil emissions is known with much greater certainty than the potential climate benefits of forest sinks.

These risks are examined at some length and lead to the conclusion that managing fossil emissions separately from biological sources and forest sinks would make better sense. This alternative approach would involve separate targets for each group that reflect the risks their concentrations and warming effects pose to our ability to influence the global average temperature.

Fossil emissions need to be reduced to zero by the second half of the century. That should be the aim. Reducing them by only half that and claiming to have managed the problem by planting forest sinks to cover the rest is a poor alternative. Not only would the sinks need to be maintained in perpetuity, planting would have to continue as long as there were any residual emissions.

Different considerations apply to biological methane and nitrous oxide. Because they do not accumulate in the atmosphere in the same way that carbon dioxide does, they do not necessarily need to be cut to zero. This is fortunate because no proven negative emissions technologies currently exist that could do so. And critically, any food production, no matter how efficient, will result in some emissions of these two gases. But they do need to be reduced and a variety of mitigation options exist or are emerging that can be deployed.

The extent to which biological emissions need to be reduced involves a judgment about what level of warming is deemed acceptable. In this context, using forest sinks to offset biological emissions is more defensible. Biological methane, nitrous oxide and trees are part of biological cycles, and the duration of the benefits forest sinks can provide is roughly aligned with the duration of warming caused by methane and nitrous emissions.

As a general observation, regardless of the level of ambition of any emissions reduction targets chosen, their rationale and expected economic and temperature impacts should be made clear and explicit. If there are reasons why the temperature objectives and emissions reduction targets for fossil emissions and biological emissions are different, these should also be clearly stated.

Chapter five applies the conclusions of chapter four to New Zealand's circumstances. After considering the *current approach*, which, in the pursuit of a least-cost approach has treated all sources and sinks as substitutable, the *alternative approach* of separating the management of fossil emissions from biological emissions is tested. Modelling was carried out using the same models as those used by the Productivity Commission in its recent report on transitioning to a low-emissions economy. Where the Productivity Commission proposed a distinction between short and long-lived gases, the modelling exercise for this report compared the current approach with an alternative that separated fossil from biological emissions.

The least-cost objective that underwrites the current approach is questioned on the basis that while the short-run costs of relying heavily on forest offsets may be lower, they may be at the expense of delaying serious action on reducing gross emissions and leaving the country more vulnerable to the damage climate change is expected to inflict.

The modelling provides a feel for the long-term environmental and economic consequences of the two different approaches. The 2050 target year currently being considered by the Government was extended to 2075, which is in line with the general language of the Paris Agreement. There is nothing magic about 2050.

Not surprisingly, the big difference between the approaches – two separate targets and limiting access to forest sinks to offset biological emissions – produced important differences in outcomes. In the alternative approach, the cost of mitigation for fossil emitters is higher without access to forest sinks (even allowing for some access to international units). Biological emissions – which are modelled to be reduced by 20 per cent or 100 per cent below current levels on a net basis including forest sinks – face a lower cost of mitigation.

But the most striking difference in real-world outcomes is the extent of land use change. Unconstrained access to forest sinks in the current approach sees 5.4 million hectares of land switched to forest cover. Under the most stringent requirements the alternative approach sees a conversion of between 1.6 and 3.9 million hectares.

New Zealand is not exactly short of land. It can easily accommodate more forestry. But making all land potentially available for storing carbon (as a substitute for not emitting it) will inevitably limit land use choices and options. A different dynamic is at work if only biological emissions can be offset with trees.

Under the current approach, the physical, economic and social shape of the landscape will be determined by decisions taken in residential and industrial New Zealand and on our roads and in our skies, as well as by international commodity prices. Under the alternative approach, there would still be many more trees planted, but the landscape would be shaped by the industries and communities who currently live and work there.

The modelling suggests that any increase in forest area would be strongly skewed to three regions – Canterbury, Otago and Manawatū-Whanganui. Significantly, the two South Island regions are predicted to become more vulnerable to extreme fire risk, further underlining the risks that a heavy reliance on forest sinks might carry.

Modelling of the type undertaken inevitably paints a stark picture of winners and losers. Governments have to deal with real businesses and communities that cannot adapt overnight and consumers who will ultimately wear the inevitable costs that flow through into the cost of living. In the same way that the expected temperature impacts of targets should be able to be transparently described, credible transition pathways that are economically and socially sustainable also need to be able to be debated.

Transitional policies should aim to enable a steady transition – one in which emitters are neither overly disrupted nor so protected that there is no incentive to change.

For fossil emitters there are insights from the modelling that many new low-cost abatement technologies are available that will soon be commercially viable. For sectors lacking those technological pathways, a variety of possibilities exist to provide support through international permits, some transitional ongoing access to forestry offsets or free allocations.

For biological emitters the introduction of an emissions price would need to be at a pace that would allow time to develop efforts to improve on-farm measurement to accurately estimate emissions at the farm level and deploy new management techniques.

Demand for forest offsets would come from biological emitters instead of fossil emitters in the NZ ETS. Land use change would be driven largely by landowners seeking to rebalance the natural capital on which they depend rather than a completely external grab for 'sink space' by the fossil economy.

Placing biological methane and nitrous oxide emissions together with forest sinks in the same policy 'basket', separate from fossil emissions, would underscore the fact that these biological sources and sinks are often co-produced and co-managed in New Zealand landscapes.

Treating them together has the potential to optimise both economic and environmental outcomes and provide the basis for a more integrated, landscape-wide approach to managing the environmental impact of New Zealand's land-based sectors.

Chapter six provides some feel for what the alternative approach might mean at the level of an actual catchment. As a case study, the two climate policy approaches described in chapter five we applied to the Hurunui catchment in Canterbury. The results of a mix of modelling and consultations are described, which try to highlight some of the economic, social and ecosystem consequences of the different approaches.

The case study was designed not just to show what impact the different approaches would have in purely climate mitigation terms, but also a wide range of economic and environmental outcomes, including changes in the productive use of land, employment, water quality, biodiversity and cultural and recreational values.

Unsurprisingly, both approaches see an increase in forest area. But the scales are very different, with the alternative approach potentially providing a much less monolithic change in land use with more socially and environmentally sustainable outcomes.

Building on these insights, the chapter develops some very preliminary thoughts on what a 'landscape-based' approach to managing climate and other environmental challenges could mean for our land-based industries and rural communities. This approach would see the landscape as more than just a place for storing carbon. Rather, it would focus on the landscape as a place in which a wide range of interrelated environmental, social and economic services are provided.

Making such an approach work would depend on being able to integrate all that we know about environmental processes at the landscape scale with bottom-up, grass roots knowledge. That in turn relies on willing landowners and communities taking ownership of many problems currently associated with land use practices.

Ideas like this can remain just that – lofty ideas lacking a means of implementation. Fortunately, using emissions pricing as a way to incentivise changes to land use and land management provides an important source of revenue to facilitate the transition. Revenue from the pricing of biological emissions could be, in part, directed back to the landscapes and communities from which they came. That revenue could be used to support tree planting and related activities designed to reduce the risks of climatic and economic disruption.[4]

Some tentative conclusions

This report was written in part to challenge the premise that the current approach to thinking about target setting and climate policy is beyond question. That there are alternative ways to think about the issue, which would impose different costs and run different risks. Policymakers need to be prepared to test different approaches rather than accept without argument that 'there is no alternative'. There are always alternatives.

In my judgment, removing access to forest sinks for fossil emitters would be prudent recognition that we do not know how to manage the risks of maintaining impermanent sinks over the timescales needed to match the long-term warming associated with fossil carbon dioxide emissions. It would send a strong signal that since carbon dioxide is the main driver of global temperature rise, serious climate action to tackle New Zealand's gross fossil carbon dioxide emissions can be delayed no longer.

But forestry still has a vital role to play. Using forestry to offset biological emissions makes more sense, as forests and farms are part of the fast biological carbon cycle and nitrogen cycle, and the durations of the warming impacts of biological emissions are better aligned with the duration of the benefits of trees. And forestry can supply a wide range of other benefits.

Parliament will be asked to legislate for a long-term target or targets. In broad terms, that target must reflect the ambition of the Paris Agreement. What that means in a domestic context has now to be determined. Whatever target is chosen has to be durable over time. I have already recommended that final targets should only be enshrined in law once they have been carefully considered by the new Climate Commission. The recommendation of the commission provides the best chance that any target or targets can command enduring cross-party support.

I would simply note that the alternative approach developed in this report would enable a zero gross fossil emissions reduction target to be set for fossil carbon dioxide sometime in the second half of the century, with clear progress made towards this target by 2050.

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4 The scale of the revenues is likely to be sizeable. For example, modelling the alternative approach in the Hurunui catchment suggested that between now and 2050, up to $640 million could potentially be available to the catchment that generated it, if these funds were returned to this landscape alone.

This is not as daunting as it sounds. Over the last 50 years, we have seen cars change from heavy old gas guzzlers to electric vehicles that can travel over 500 kilometres on a single charge. We have seen the rise of solar and wind power at scales undreamed of half a century ago. It is no longer wishful thinking to imagine a future with zero fossil fuel emissions.

For biological methane and nitrous oxide, however, a different target could be set. As an agricultural leader, any action taken by New Zealand to mitigate biological emissions will be noted internationally. While the target level of emissions does not necessarily have to be zero, it has to relate to a temperature outcome that is scientifically defensible and one that we would argue other countries should aspire to. Whatever the level set for biological emissions, forest sinks are a legitimate source of mitigation.

Such an approach would make the rationale and expected economic and temperature impacts of any targets transparent in a way they are not under a net zero-all-sources-and-sinks approach. In very simple terms, New Zealand policymakers must decide whether they wish to score a net zero accounting triumph in 2050 (or some other target year) by storing carbon in forests over large areas of New Zealand; or, adopt a more ambitious approach to reducing fossil emissions and make a transparent statement about how far biological emissions should be reduced.

The current approach runs the risk that we will achieve net zero emissions with gross fossil emissions still running at around half today's level and still need more time and land to offset the balance well into the second half of the century.

Ultimately there is no avoiding a move to zero gross fossil emissions, since halting runaway climate change at any temperature level requires no further injections of fossil carbon to the atmosphere. Storing the waste from fossil emissions in forest sinks is simply delaying the inevitable.

When climate negotiations were in their early days that might have been a justifiable approach – although even then scepticism was expressed about whether the time that was being bought would be put to good use. The sceptics have been proved right.

Far from using the intervening years to push for significant decarbonisation of transport and industry, New Zealand has increased its gross fossil carbon dioxide emissions by 35 per cent since 1990. Furthermore, a net loss of 50,000 hectares of planted forests occurred between the passage of the Climate Change Response Act in 2002 and the end of the first commitment period of the Kyoto Protocol in 2012. Can we be so sure that 'this time it will be different'?

New Zealand must report and account internationally for its emissions using whatever metric is for the time being agreed. But how it goes about reducing them is entirely its business. After 25 years' debate about how to make progress there appears to be a widespread desire to do something.

What that 'something' involves has to be responsible in terms of the risks that are being run, must be delivered within a time frame that is manageable and take account of the country's unique emissions profile. Targets and policies need to be informed by science and economics. This report tries to add to understanding under each heading. But it cannot replace the need for judgments that are ultimately ethical and political ones.

From this lengthy investigation I have just three recommendations for Parliament as it moves to consider the Climate Change Bill:

- Develop two separate targets for the second half of the century: a zero gross fossil emissions target to be legislated as part of the establishment of the new Climate Commission; and a reduction target for biological emissions to be recommended by the new Commission and subsequently legislated. A later date than 2050 would still be consistent with the Paris Agreement and should not be ruled out if that is considered to be a more credible and achievable time frame within which to effect such a significant economic transformation.
- Allow access to forest sinks as offsets only for biological emissions on a basis to be advised by the Climate Commission.
- Develop the tools needed to manage biological sources and sinks in the context of a landscape-based approach that embraces water, soil and biodiversity objectives.

Taking a landscape-based approach is all about how landowners and communities are incentivised to act. Policy tools will be needed that go beyond simple economic instruments or regulations. However, the use of emissions pricing revenues could be a powerful additional tool to support land users making significant changes to the landscapes they live in.

Finally, I would urge policymakers to focus steadily on the long term in setting these targets. There will be all sorts of compromises and trade-offs to be made in the early emissions budgets as the transition is commenced. There will inevitably be disagreements about emphasis and technique. But the long-term targets should not be held hostage to these arguments.

I am in no doubt about the scale of the challenge policymakers face. Any serious attempt, in good faith, to start the economic transformation required by climate change will have my support. I hope this report can assist a wide range of people to think about what that transformation could mean at the level of the landscape and the risks that need to be managed.

Simon Upton

Parliamentary Commissioner for the Environment

Tirohanga whānui

He pūrongo tēnei mō te ara hou ki te tāparepare i ngā whāinga panoni āhuarangi me ngā kaupapa here karioi o Aotearoa, ā, ka ahatia ō tātou horanuku. Inarā me pēhea tā tātou whakahaere ngātahi i ō tātou haurehu kati mahana ahuwhenua me ō tātou whakatotohu ngahere, ā, ka motuhake te whakahaere i ngā putanga hauhā mātātoka.

Ākuanei ka taupatupatu te Pāremata i te ture e whakarite ai i te whāinga whakaheke putanga karioi mō Aotearoa. I konei ko te tikanga o karioi ko te tau 2050. Arā, me whakaae ki te whāinga roa ake i ngā umanga pāremata o tata ki te katoa o ngā mea kua pōtitia ki te Whare o Raro ināianei. He roa rawa te ātārangi o te anga e whakatūria ai.

Kia tutuki ai i ō tātou whāinga karioi me kite i ngā kaupapa here me ngā auaha kāore anō kia hangaia. He tino tika tēnei mō ngā putanga koiora i te ahuwhenua, ākuanei tirohia ai mō te wā tuatahi. Kua rau tau ngā horanuku o Aotearoa e akaaka ana. Ko te ara tāparepare i ngā whāinga e pā ana ki ngā mātāpuna koiora me ngā whakatotohu e tuhi ai i te wāhanga hou mō te huringa horanuku.

Ko taku kupu āwhina ki te Pāremata i tērā tau ko te mahi tuatahi a te Kōmihana Āhuarangi ko te tuku kupu āwhina mō tō tātou whāinga karioi. Koinei tonu taku kupu āwhina. Engari kāore anō te Kōmihana kia whakatūria. Nā reira kua whakatatū au māku e tuku ētahi whakaaro mō te kaupapa nei.

He whakapuaki aronga - me te takohanga

He tika pea kia timata tēnei tirohanga whānui ki te whakapuaki aronga. He kaha taku whakamahi i te kora mātātoka – pērā i te nuinga o ngā tāngata o Aotearoa, te nuinga o te wā hei kirirarau hāereere. Ka haere au mā runga wakarererangi, mā runga motokā hoki. Ka noho au i runga i te pāmu i whānau ai au. Ka whaipānga taku whānau ki te pāmu me te ngāherehere. Nā reira, kei roto au i ngā ohaoha mātātoka me ngā ohaoha koiora. Nā, he ōrite tēnei āhuatanga ki ngā tāngata maha o Aotearoa. Ehara tēnei pūrongo i te tuhinga tūrehurehu noa iho. Ka pā atu ki ngā tauoranga o tēnā, o tēnā o tātou.

Mōku ake, kāore e mutu i reira. He haepapa pea tāku mō te whanaketanga o te kaupapa here āhuarangi. Ā-motu, i pau ngā 1990 hei Minita e whakamātau ana ki te mārama he aha te tikanga o te urupare ki te Anga Kāwenata Panoni Āhuarangi o te Rūnanga Whakakotahi i Ngā Iwi o te Ao, ka tahi, me te Tikanga o Kyoto, ka rua, mō te kaupapa here taiwhenua i Aotearoa.

Ka rangahaua e au ngā tāke me ngā whakangārahu hokohoko putanga. Ā, ka tirohia e au te whakawhanaketanga o te tūranga whiriwhiri i hoatu i te tāwariwaritanga whānui ki ngā motu pērā i Aotearoa kia āhei ai te whakamahi ōrite i ngā mātāpuna me ngā whakatotohu hei rīwhi, tētahi mō tētahi, mā te whakamahi i te ine ōrite. E pēnei ana te whakarāpopoto o tēnā ara:

"Ko te tāpaetanga whakamau ki te kōhauhau o ngā haurehu kati mahana te mea nui ahakoa he aha ngā mātāpuna, ngā whakatotohu rānei. Ki te whakaiti i te utu o te whakaheke putanga, he pai ngā momo mahi katoa mēnā ko te nuinga o ngā haurehu – i whakaritea mō te āheinga hihinga whakamahana mā te tango i te whakatotohu – ka ārahi tātou ki te ara whakaheke." [1]

Me whakarite te ine ōrite kia tāea ai e ngā motu te whakarite i ā rātou mahi ki te hōputu ōrite.

Engari, i Aotearoa, he mea nui hoki kia whai i te kaupapa here whakamauru ki te utu iti rawa.

Ā, mō Aotearoa, ko ngā ngahere te huarahi utu iti ki mua. I te tīmatanga o ngā 1990, i a mātou ngā ngahere whakatō nunui e tere tipu ake ana, i koa mātou ki te kaute i te huna waro i tohua e aua ngahere ki te whārite. Tēnā, ko te whāinga taiwhenua tuatahi o Aotearoa i whakawhanaketia i runga i te whakaaro e 20 paihēneti ki te whakaheke putanga, ā, e 80 paihēneti ki ngā whakatotohu ngahere kia whakatutukihia.

Tērā ngā kaiwhakahē ki tēnei ara. Inakuanei i ketuketua e au tētahi kōrero i kōrero ai au i te 25 tau kua pahure ake nei, i whakautu au ki tētahi o ngā kaiwhakahē, Greenpeace, e pēnei ana: "Ki tā te pūtaiao, kāore e taea te whakahē i te kōrero he ōrite te ngota waro kua rakaina (hunaia) ki te ngota waro kāore i whakaputaina ki te kōhauhau."

Tērā pea i pēnei taku here i taua kōrero: "Kāore tētahi e whakapae ana ko ngā whakatotohu te whakautu katoa. Kāore te whakatotohu e tū mō ake tonu atu – ka pau tō tātou nama kia tae ki te tau 2020." Engari, kāore taku raru ki te whāki ko te tino whānui o ngā whakatotohu ngahere i taua wā (me te tawhiti atu o te tau e 16 tau ki mua i te wā e 36 ō tau) i āhuareka te karo hei kaupapa here urupare whakamanea.

I te wā i werohia mātou ki te whakahē nei, arā, tērā pea ka uhia te motu ki ngā rākau engari kāore e whakahekea ngā putanga mātātoka, i whakapae au he arawhata ēnei ki te wāmua putanga iti, ā, ko ngā whakatotohu ngahere he ara utu iti i ā tātou e tatari ana kia whakawhanakaetia ngā hangarau hou. Nā te mea, i tō tātou motu ētahi putanga uaua rawa ki te whakaheke – arā noa ērā nō te ahuwhenua – he ara whakamua.

Kāore taku takohanga e mutu ki kōrā. Nā te mea, tata ki te tekau tau i mua, i muri iho i te taumata āhuarangi mūhore o Kopanahekana i tīmata au ki te whakarewa i te taupatupatu ā-ao mō te whāinga whakamutunga me whai ngā whāinga panoni āhuarangi me ngā kaupapa here.

Nā whai anō, i te tau 2013, ka whakaritea e au te kauhau i tukuna e te Hekeretari-Tianara o te Rōpū mō te Mahi Ngātahi me te Whakatipu Ohaoha o taua wā, i whakahau ia kia "whakamutua rawatia ngā putanga katoa ki te kōhauhau i te tahu i ngā kora mātātoka i te wāhanga tuarua o te rautau".[2]

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[1] Upton, 2018.

[2] Gurria, 2013.

Konei te wā tuatahi i tūhonoa e tētahi rangatira nui o te ao te mea i mārama rawa i roto i te pūtaiao āhuarangi mō ngā tau 20, neke atu rānei, me te hiahia ki te angawā ka ngau ngā kaupapa here mēnā ka herea ngā pikinga o ngā paemahana toharite ā-ao kia kaua e nuku atu i te rua tākiri tohurau.

Ka ōrite taku whakaaro ki te tūraru nui e puta mai ai i te whakatōhenehene āhuarangi a te tāngata me te hiahia kia tere te mahi. Ko te wero whakahaere tūraru karioi kua whitawhita i te kore tutuki o ngā whakaeaea kaupapa here. Nāku anō tētahi wāhanga o te hē.

He aha ngā rerekētanga?

Nā te Whakaaetanga Pārihi o 2015 i whakarerekē i te āhua o te taupatupatu ki ngā āhuatanga e rua. Ka tūtohu mō te wā tuatahi ko te tūturutanga pūtaiao me mutu te kaha whakamahi o ngā ohaoha i ngā kora mātātoka, ā, i roto i ngā tekau tau torutoru noa iho. Tuarua, ka mutu te rapunga mō te ao pai rawa atu mō te whakarite ā-ao i ngā roherohenga putanga ā-motu i tohaina mai i runga. Engari, i waiho ki ngā motu ki te kī ka pēhea rātou e tāpae kia ea ai te "whakataurite i ngā putanga ā-tāngata mā ngā mātāpuna me te tangohanga mā ngā whakatotohu i ngā haurehu kati mahana i te wāhanga tuarua o tēnei rautau".[3]

Ko tēnei ara 'mai i raro' i whakamanawahia au kia whakaaro mō te rerekētanga o ngā tūmomo haurehu o te tāpaetanga o Aotearoa ki te whakamahana o te ao, te pono o ngā whakatotohu ngahere hei karo i ngā putanga hauhā me te hiahia kia ahu whakamua i ngā haurehu katoa i roto i ngā tekau tau e rima.

Tae mai ki tēnei wā, i tīmata te taupatupatu i ngā kaupapa ōrite: ko ngā mātāpuna haurehu kati mahana me ngā whakatotohu ka tū hei tino rīwhi, tētahi mō tētahi; ā, me kite tātou i te ara utu iti o te whakaaweawe i te huringa ohaoha e hiahiatia mō ngā whāinga whakahekenga putanga.

Ko te whakakotahi i ngā marohi e rua ka hanga i te tauranga whāiti mō ngā kaupapa here – tētahi pūrere utu tāwariwari nā reira e tautoko ana i te hōpara mō ngā auaha hangarau, me ngā auaha whakahaere, utu ihi ahakoa kitea ki hea. Mēnā ka taea e tātou te hanga i te utu putanga tika, mā te mākete te toenga.

Koinā tonu tētahi ara ki te whakamahi i te raru. He purotu, he māmā hoki tēnei e hahae nei i te uaua o te ohaoha ao hurihuri, ā, ka here i te āheitanga kōkirikiri. Ā, kei roto i tō tātou Whakangārahu Hokohoko Putanga (NZ ETS) te hoahoanga mō te ara pērā. Ko te whakamāramatanga mō te take kāore he utu ā-ohaoha ko te kore kaha tōrangapū – he whakamaharatanga ahakoa ngā āhuatanga hokohoko, ko te whakangārahu hokohoko putanga he tamaiti nā te tōrangapū.

Ehara tēnā i te take kia whakahēngia. Engari me whakaaro tātou tērā pea ko ngā kaupapa taketake kua whakaponohia e tātou mō te wā roa, kāore pea e tū tonu, ina rā te kokoraho ko ngā mātāpuna haurehu kati mahana me ngā whakatotohu he tino rīwhi tētahi ki tētahi.

[3] Whakaaetanga Pārihi, Article 4.1 Hakihea 2015.

I ngā motu maha, ko te tahu i ngā kora mātātoka te tino nuinga o ngā putanga, he take kāore e tino arohia ana. Engari i Aotearoa, ko tētahi wāhanga nui o ngā putanga i puta i ngā mātāpuna koiora, ā, ko ngā ngahere e whakaarohia ana hei aho nunui ki te homai i te whakahekenga utu iti, he kaupapa me āta whakaaro. He mea i tino whakaaetia e au i mua. Kāore e pēnei ana i tēnei wā.

Kua whakatau au ko tō tātou kaupapa ināianei kāore i te tika. Ka whakamātau ki te whakakotahi i ngā tini āhuatanga rerekē ōkiko mō ngā haurehu e whakaputa ana mātou ki te taurangi kotahi. Ko te hipa i ēnei rerekētanga ōkiko he tūraru mō ngā motu pēnā i Aotearoa. Ahakoa he pai rawa mēnā ka kitea he whakatika mai i te pūtaiao, kāore anō kia kitea. Ko ngā hurihanga koiora matū whenua o te ao e rawekehia e tātou he tino pīroiroi, ā, he maha ngā whakaohorere kei te haere mai. Engari e mōhio ana tātou kāore e ōrite ngā haurehu katoa.

Ahakoa he pai, he ngāwari te anga ināianei ki te ine i ngā haurehu, ehara i te kaupapa pai mō ngā whakamauru āhuarangi karioi. Koinei te take, ki taku nei titiro, me rerekē te tirohanga, ka tika, a Aotearoa ki ngā mātāpuna mātātoka, koiora hoki, ki tērā mō ngā whakatotohu. He hīraunga mō te ara e whāia e mātou ki te tautuhi i tō tātou whāinga karioi me ngā kaupapa here e whāia kia tutukihia.

I runga i te kaupapa me whakatutuki ngā whāinga me ngā kaupapa here ki te utu iti e āhei ana, kāore e pēnā te nui o aku māharahara. He utu mō ngā kaupapa here āhuarangi. Ka whakatūturutia noatia mēnā he pai ki te tirohanga a te hapori whānui. Nā reira, me mātua whakaaro ki te utu *i ngā wā katoa*.

Ko te wero kē, kia mārama he aha ngā utu e kōrerotia ana e tātou, ka utua e wai, ā, he aha ngā angawā. He aha ngā tūraru o ngā rautaki rerekē? Ko ngā haurehu e rapu ana tātou kia herea ka noho haepapa mō ētahi mea atu i te whakamahana o te ao. Ka whakaaweawetia ētahi atu wero taiao mai i te whakapaparanga hāora-toru ki te whakawaikawa moana. Pērā tonu ngā rākau ka whakatōngia ki te karo i te whakamahana, ka hoatu i ētahi atu painga taiao. Engari, nā te mea, me tū tonu mō ake tonu atu, me mārama tātou ki ngā kōwhiringa e katia ana e tātou.

Ko ngā tukunga iho karioi o ngā ara rerekē mō te whakahaere i ō tātou haurehu kati mahana te take kāore i whāiti te tirohanga ki te whakamahana, ā, ka tirohia kētia he aha te huringa horanuku e tae mai ai ki a tātou. Nā te taumaha o te wero āhuarangi, ki te tutukihia e mātou, ko te āhua me te anga o tō tātou ohaoha ka rerekē rawa ahakoa he aha te huarahi e kōwhiria ai e tātou. Ka tika tēnā mō ngā hapori katoa. Waihoki, ki te kore tātou e tutuki i te wero, ka hurihia tō tātou ohaoha me tō tātou taiao, engari kāore e pērā te rerehua.

Mō Aotearoa nei, i runga i te āhuatanga koiora o tō tātou ohaoha, ko te ara e urupare tātou ki te panoni āhuarangi ka whakaputa i ngā tukunga iho ōkiko, ā-taiao, ā-ataata, ā-hapori hoki e tino kitea i tō te ohaoha ahumahi, ohaoha ratonga rānei. Ko te āhuarangi kotahi anake o ngā uauatanga e tūkino ana i ō tātou horanuku. Te wai parakino, te whakapau oneone, te ngaro o te kanorau koiora me ngā urutomo riha ētahi noa iho o ngā tūraru e whakaarohia ana e tātou – he mea whakanui e te panoni āhuarangi.

Ki te anganui ki ngā whakahekenga putanga me mōhio tātou ki ngā tukunga iho e whai ake nei mō ēnei wero taiao. Me mōhio hoki tātou ki ngā whāmere me ngā hapori, ngā whānau me ngā hapū e noho ana ki ngā wāhi e whakaputa tātou i te haurua o ō tātou haurehu koiora (mewaro me te hauota-rua ōkai) me te whakaaro ki te whakaputu i tō tātou para waro. E hiahia ana mātou ki tētahi mea i tua atu i te ara kaute mō ngā whāinga āhuarangi me ngā urupare kaupapa here e whakaata pai ai i te pūtaio ōkiko me ngā tūraru e pai ana ki a tātou.

Ko te whakapae o te pūrongo

He pūrongo roa tēnei. Ko te whakarāpopototanga o te whakapae e whai ake nei. Atu i te whakaatu i te ara rerekē ki te tāparepare i ngā whāinga me ngā kaupapa here, ka whakakotahi te pūrongo roa i ngā hua o ngā rangahau maha. Nā reira, ko ngā upoko tahi ki te toru he whakakotahitanga rangahau e taea ai te whakahoki hei tohutoro mēnā e hiahiatia ana ngā whakamārama hōhonu. Ko ngā kaipānui e hiahia ana ki te hōrapa i ngā kitenga nui e pā ana ki te kaupapa here me titiro ki ngā upoko whā ki te ono.

Upoko tahi ka whakarite i te tirohanga mā te kōrero mō ngā whakataunga kaupapa here o nāianei i roto i te horopaki o te hītori me te whakawhanaketanga o Aotearoa. Mai i te wā tuatahi o te nohonoho mai – he wā iti iho i tētahi atu wāhi i te ao – kua tīmata ngā tāngata ki te whakahuri i te horanuku i ngā ara i whakaarohia ai, me ngā ara kāore i whakaarohia ai.

I te hātepe nei kua tino whakarerekētia te whakahaere o te hurihanga waro māori.

Ko te tino tāpaetanga o Aotearoa ki te panoni āhuarangi o te ao ināianei kua puta mai i te maha rawa o te waro kua whakaputaina mai i te whenua – ōna ngahere me ōna oneone – ki te kōhauhau. He nui ake tēnei i te nui o te hauhā kua whakaputaina i te tahu o ngā kora mātātoka.

He raupapa huringa horanuku i whakamahia i Aotearoa. I te tuatahi ko te whakaheke ngahere i whakamahia e ngā hiahia o ngā tāngata nohonoho nō Te Moananui-a-Kiwa me Ūropi. Nā, i te tūhononga o Aotearoa ki te hokohoko ā-ao, ko ngā whakarerekētanga ki ō tātou horanuku i whakamahia e ngā kiritaki i tērā taha o te ao.

Ko te whakaheke ngahere i te whāinga ki te ohaoha tarutaru te mea hou. Ko te whakahoki ngahere i whakamahia e te whakawhanake o te ahumahi whakatō ngahere. Ko ngā pūtea tāpiri i whakauruhia hei tautoko i te ahuwhenua i tino whakariroi i te whakamahi whenua. Nā te whakakorenga o aua pūtea tāpiri i hūkeke ai ō tātou horanuku me te wā hou o te whakamarohi me te kanorau e haere tonu ana tae noa ki tēnei rā.

Hei whakarāpopoto, kua kitea e Aotearoa he raupapa whakarerekē whakamīharo i te uhi whenua me te whakamahi whenua, nā tēnā rerekētanga, nā tēnā rerekētanga i whakaneke i ngā rahinga waro tino nui. Ko te ara e whāia e tātou hei urupare i te panoni āhuarangi e aki anō ai i te whakarerekē whakamahi whenua me te ara e wawao ai tātou ki te hurihanga waro.

Upoko rua me te toru e kimi ana ki te hoatu ki te kaipānui i te kōrero hou mō te māramatanga o te pūtaio e pā ana ki te mahi whakarerekē i te ao a ngā mahi tāngata, ā, he aha te āhua o ēnei mahi ki Aotearoa.

Upoko rua ka whakaatu i ngā āhuatanga ōkiko rerekē o ngā haurehu e toru e kaha tāpae ki te whakamahana a te tangata i te ao – hauhā, mewaro me te hauota-rua ōkai. Ka whakaatu i ngā hurihanga koiora whenua matū e whakanuku i te waro me te hauota ki te ao. Kua āta whakaatu au i ēnei hei rauemi mō ngā tāngata e hiahia ana ki ngā pīroiroitanga – he maha ērā – ki tautoko anō hoki i ngā whakataunga i roto i te pūrongo mō te painga o te whakaaro he ōrite ngā mātāpuna me ngā whakatotohu hei rīwhi, tētahi mō tētahi.

Kia mārama ai ki te whakaaweawe e haere tonu ana me ngā urupare kaupapa here pai, me whakaaro i pēhea aua haurehu i whakaputaina, i tautokohia rānei te whakaputa, ā, he aha te tūhononga o ngā whakaaweawe, tētahi ki tētahi.

Whai muri i te whakaatu i te pūtaiao, **upoko toru**, e whakaatu ai i te tāpaetanga o te hauhā, te mewaro me te hauota-rua ōkai ki te whakaritenga putanga i ngā 200 tau kua pahure ake nei. Ka whakamahere i te ara o ngā rautau e rua me te whakarerekē tonu o te whakamahi whenua i runga i te pahū me te pakaru o ngā rauemi hoko i whakaahua i te horanuku o Aotearoa.

Ahakoa ko te nuinga o te whakaaro e hāngai ana ki ngā haurehu kati mahana ahuwhenua, ko te whakarerekē whakamahi whenua te tino tāpaetanga a Aotearoa ki te whakamahana ao.

Neke atu i te 3 piriona tana o waro kua whakanekehia ki te kōhauhau i te whenua, i te nuinga o te wā nā te whakaheke ngahere mō te ahuwhenua. Ko te whakatau tata o te taumaha o te whakamahana o ēnei whakarerekētanga whakarea mā te whitu te tāpaetanga o ō tātou putanga mātātoka.

Ko te urupare ki te panoni āhuarangi – me te whakamahi i te maha noa atu o ngā taumahatanga taiao e whakaaweawe ana i ngā tāngata o Aotearoa ki te whakaaro mō te ara e whakamahia ai, e whakahaeretia ai, te whenua. Ko tētahi kōwhiringa ko te whakaputu i ētahi atu waro ki te whenua i roto i ngā rākau. Ahakoa he maha te whenua mō te whakahoki ngahere, ko te ara me te whānui me āta whakaaro.

Ahakoa he roa te tauoranga o ngā ngahere, ehara i te tauoranga pūmau. Kei te piki te whakapā o ngā pānga panoni āhuarangi ki ngā ngahere mā te ahi, ngā riha, ngā tukumate me te ngāhorohoro, e tīpako ana te āhua memeha. Nā ēnei tūraru me te kore e tino mōhio e pā ana ki ō rātou painga paemahana, he tūraru e puta mai ai i te kaha whakawhirinaki ki ngā karo ngahere.

Upoko whā ka whakaputa i te whakapae nui e pāitaihia ana e te pūrongo nei: me whakaaro tonu tātou he ōrite ngā mātāpuna me ngā whakatotohu ā-tāngata, he rīwhi tētahi ki tētahi, i te wā e whakarite ana mātou i ngā whāinga whakaheke putanga me te whakarite i ngā kaupapa here whakamauru panoni āhuarangi?

Te āhua nei, ki te ara onāianei, kāore he māharahara ki tēhea haurehu e tirohia ana, mēnā e āhei ai te whakaōrite i ngā tauoranga me ngā kaha o ngā haurehu. He ōrite te whakaaro i raro i te kaupapa e kī ana ko te waro i hunaia, i rakaina hoki ki ngā rākau ka tino karo i te whakaaweawe o te hauhā, te mewaro me te hauota-rua ōkai ahakoa he aha te mātāpuna.

Ahakoa he tika tēnei mō te mahi kaute, ko te rerekētanga ao tūturu i waenganui i ngā tino haurehu kati mahana, e whakaatu ana kāore e ōrite ngā tūraru o tēnā haurehu, o tēnā haurehu. E rua ngā tūraru nui ki te ara onāianei e whakaatuhia:

- Tuatahi, he whāinga kotahi e whakakotahi ai i ngā mātāpuna me ngā whakatotohu e whakapūrehurehu ana i ngā tukunga iho o ngā kaupapa here. Ki te kore tētahi whāinga tautuhi e whakaritea mō ngā putanga mātātoka hauhā katoa, ka taea te whakaheke kē i ngā putanga mewaro, hauota-rua ōkai rānei, kaua ko te whkaheke hauhā mātātoka. Heoi anō, kāore ngā whakakotahitanga o ngā whakahekenga e whakaputa I ngā tukunga iho paemahana ōrite.
- Tuarua, ko te hauhā mātātoka i whakaputaina ki te kōhauhau ka whakaputa i te whakaaweawe whakamahana mō ngā mano tau. Hei whakatairitenga, ko te waro i whakaputua ki ngā rākau me ērā atu pūnaha hauropi whenua ka whakaputaina wawetia ki te kōhauhau ki te tae mai he ahi, he riha, he tūraru anō hoki. He nui ngā tūraru o te whakaputa tonu i te hauhā mātātoka i runga i te kaupapa he ōrite te maha o te waro i hunaia ki ngā whakatotohu koiora.

Waihoki, te tino wā roa o te whakaaweawe whakamahana o te hauhā mai i ngā putanga mātātoka e tino mōhiotia ana, engari kāore e pērā ngā painga āhuarangi o ngā whakatotohu ngahere.

Ko ēnei tūraru e āta tirohia ai, ā, ka tautoko i te whakataunga he pai ake te whakahaere kē i ngā putanga mātātoka me ngā mātāpuna koiora, whakatotohu ngahere hoki. Mā te ara rerekē ka whakatū i ngā whāinga rerekē mō tēnā rōpū, mō tēnā rōpū, e whakaatu i ngā tūraru e pā ana ki ngā pīhangaiti me ngā whakaaweawe whakamahana ki tō tātou taenga ki te whakaaweawe i te paemahana toharite ā-ao.

Me whakaheke ngā putanga mātātoka ki te kore kia tae atu ki te wāhanga tuarua o te rautau.

Koinā te whāinga. Ko te whakaheke mā te haurua, me te kī kua whakahaeretia te tūraru mā te whakatō whakatotohu ngahere he rīwhi kino. Tuatahi, me whakapūmau ngā whakatotohu mō ake tonu atu, me whakatō tonu i te wā e puta tonu ana ngā putanga.

He rerekē te whakaaro mō te mewaro koiora me te hauota-rua ōkai. Nā te mea, kāore rātou e whakaemi ki te kōhauhau, pērā i te hauhā, ehara i te mea me whakahekea ki te kore. He mea pai i te mea kāore he hangarau kore putanga kua puta hei whakamahi i tēnā. Ā, ko te mea nui rawa, ko te whakamahi kai, ahakoe pēhea te pai, ka whakaputa i ētahi o ēnei haurehu e rua.

Engari, me whakaheke, ā, he maha ngā tikanga whakamauru ināianei, e whakawhanakehia rānei, e taea te whakamahi.

Mō te whānui o te whakaheke i ngā putanga koiora, me whakatau he aha te taumata whakamahana e pai ana. Ki tēnei horopaki, ko te whakamahi i ngā whakatotohu ngahere ki te karo i te whakamahana e whakaaweawetia he mea tika. Ko te mewaro koiora, te hauota-rua ōkai me ngā rākau he wāhanga nō ngā hurihanga koiora, ā, ko te roanga o ngā painga whakatotohu ngahere e āhua ōrite ki te roa o te whakamahana o ngā putanga mewaro me ngā putanga hauota-rua ōkai.

He tirohanga noa, ahakoa te taumata o te hiahia o te whāinga whakaheke e kōwhiria, ko te pūtake me ngā tukunga iho ā-ohaoha, ā paemahana, me tino mārama rawa. Mēnā he take mō te rerekētanga o ngā whāinga paemahana me ngā whāinga whakaheke putanga mō ngā putanga mātātoka me ngā putanga koiora, me tino kōrero.

Upoko rima ka whakauru i ngā whakataunga o wāhanga whā ki te horopaki o Aotearoa. I muri i te whakaaro ki te *ara onāianei*, i roto i te whāinga ki te ara utu iti kua whakaarohia ko ngā mātāpuna me ngā whakatotohu hei rīwhi, ko te *ara rerekē* o te whakawehe i te whakahaere putanga mātātoka me ngā putanga koiora e whakaarohia. Ko te whakatauira i whakamahia ki ngā tauira i whakamahia e te Kōmihana Whai Hua o Aotearoa i tana pūrongo hou mō te ohaoha putanga iti. I ngā wāhi i whakarerekē te Kōmihana Whai Hua o Aotearoa i ngā haurehu tauoranga iti me ngā haurehu tauoranga nui, ko te mahi whakatauira mō tēnei pūrongo i whakataurite i te ara onāianei ki te ara i whakarerekē i ngā putanga mātātoka me ngā putanga koiora.

Ko te whāinga utu iti hei kaupapa mō te ara onāianei i pāitaihia i runga i te take, ahakoa ko ngā utu poto mō te whakamahi i ngā whakatotohu ngahere he iti iho, ko te tukunga iho ko te whakaroa ake i te tino mahi ki te whakaheke i ngā putanga katoa, ā, ka paraheahea te motu ki te kino e puta mai ai i te panoni āhuarangi.

Ko te whakatauira ka āwhina i te mōhio ki ngā whakaaweawe taiao, me ngā whakaaweawe ohaoha, o ngā ara e rua. Ko te tau whāinga 2050 e whakaarohia ana e te Kāwanatanga i whakaroa ake ki te 2075 e ōrite ana ki te Whakaaetanga Pārihi. Ehara te 2050 i te mea whaiwhaiā.

Kāore he whakaohorere, ko te rerekētanga i waenganui i ngā ara e rua – e rua ngā whainga me te whakaiti i te whakamahi i ngā whakatotohu ngahere ki te karo putanga koiora – i whakaputa i ngā rerekētanga hua. I te ara rerekē ko te utu karo mō ngā kaiwhakaputa mātātoka he nui ake mēnā kāore e whakamahia ngā whakatotohu ngahere (ahakoa ka whakamahia i runga i ētahi wāhanga ā-ao). Ko ngā putanga koiora – e whakahekea mā te 20 paiheneti, 100 paiheneti rānei i raro i ngā taumata o nāianei ki te kaupapa whakamau tae atu ki ngā whakatotohu ngahere – he iti iho te utu whakamauru.

Engari ko te tino rerekētanga ki ngā hua i te ao tūturu ko te whānuitanga o te whakarerekē whakamahi whenua. I runga i te tino whakamahi i ngā whakatotohu ngahere ināianei ka 5.4 miriona heketea e hurihia ki te uwhi ngahere. I raro i ngā ritenga uaua o te ara rerekē ka huri ki te 1.6, tae atu ki te 3.9 miriona heketea.

He maha rawa te whenua i Aotearoa. He maha ake ngā ngahere e taea te whakatō ki te whenua. Engari, ko te whakawātea i te whenua katoa mō te whakaputu waro (hei rīwhi mō te kore whakaputa) ka whakaiti i ngā kōwhiringa whakamahi whenua. He kaupapa anō tēnā mēnā ko ngā putanga koiora anake ngā mea e taea te karo mā ngā rākau.

I runga i te ara o nāianei, ko te āhua ōkiko, ohaoha, hapori o te horanuku ka whakaritea e ngā whakataunga ki ngā kāinga me ngā ahumahi o Aotearoa, i runga i ō tātou rori me ō tātou rangi, tae atu ki ngā utu rauemi ā-ao. I runga i te ara rerekē, he maha tonu ngā rākau ka whakatōngia engari ka whakaahuatia te horanuku e ngā ahumahi me ngā hapori e noho ana, e mahi ana, i reira.

E ai ki te whakatauira ko ngā wāhi e nui ake te whakatō ngahere ko ngā takiwā e toru – Ōtautahi, Ōtakou me Manawatū-Whanganui. Nā, ko ngā takiwā e rua o Te Waipounamu e matapaehia ana, ka paraheahea ki te tūraru ahi, e kaha whakaatu ana i ngā tūraru e puta mai ai i te whakawhirinaki ki ngā whakatotohu ngahere.

Ko te whakatauira pēnei e whakaahua i te rōpū e toa ana me te rōpū e hinga ana. Me mahi tahi te Kāwanatanga me ngā pākihi me ngā hapori tūturu, kāore e taea te urutau i te pō kotahi me ngā kaiwhakatange e utu i ngā utu, kāore e kore, ka rere ki te utu o te tauoranga. Pērā ki te ara e āta whakamāramahia ngā tukunga iho paemahana o ngā whāinga, me āta taupatupatu i ngā ara whakawhiti tika e toitū ana ā-ohaoha, ā-hapori.

Ko ngā kaupapa here whakawhiti me whai i te ara whakawhiti pūmau – tētahi ara kāore i tino whakatōhenehenetia, ā, kāore i tino whakamaruhia ngā kaiwhakaputa, kei kore e whakapoapoatia te whakarerekētanga.

Mō ngā kaiwhakaputa mātātoka he kitenga mai i te whakatauira tērā atu hangarau whakaheke iti utu kua hangaia e pai ai te hoko akuanei. Mō ngā rāngai kāore e whai ana i aua huarahi hangarau, tērā ngā momo āhuatanga ki te tautoko pērā i ngā puka whakaaetanga ā-ao, me te āheinga whakawhiti ki ngā karo ngahere, ki ngā toha kore utu rānei.

Mō ngā kaiwhakaputa koiora te tīmatanga o te utu whakapuuta me tuku i te wā kia taea te whakawhanake i ngā mahi ki te whakapai i ngā ine ā-pāmu kia tika te whakatau tata i ngā putanga i runga i ngā pāmu me te whakamahi i ngā tikanga whakahaere hou.

Ko te tono mō ngā karo ngahere e puta mai i ngā kaiwhakaputa koiora, kāore e puta mai i ngā kaiwhakaputa mātātoka i roto i te NZ ETS. Ka ākina te whakarerekē whakamahi whenua e ngā kaipupuri whenua e titiro ana ki te whakataurite i te moni hua e hiahiatia ana e rātou, kaua ko te mahi o waho e pā ana ki te whai i te ‘takiwā whakatotohu’ a te ohaoha mātātoka.

Ko te whakanoho i ngā putanga mewaro koiora me ngā hauota-rua ōkai ki te ‘kete’ kaupapa here ōrite, whakawehetia ai i ngā putanga mātātoka, ka tautoko ko ngā mātāpuna koiora me ngā whakatotohu he wāhanga i whakaputa, i whakahaere rānei, ki ngā horanuku o Aotearoa.

Ko te whakamahi ngātahi ka whakapai ake i ngā hua ohaoha me ngā hua taiao me te hoatu i te kaupapa mō te ara ngātahi, ki ngā horanuku katoa mō te whakahaere i te whakaaweawe taiao o ngā rāngai whenua o Aotearoa.

Upoko ono ka whakaatu i te ara rerekē ki te taumata o te takiwā awa. Hei kēhi rangahau, ko ngā ara kaupapa here āhuarangi e rua, i whakaatuhia i upoko rima i whakamahia ki ngā awa o Hurunui i Ōtautahi. Ko ngā hua o te whakatauira me ngā kōrerorero i whakaatuhia hei tīpako i etahi o ngā tukunga iho ā-ohaoha, ā-pāpori, ā-pūnaha koiora hoki o ngā ara rerekē.

Ko te kēhi rangahau i whakaritea kia whakaatu i te whakaaweawe o ngā ara rerekē ki ngā whakamauru āhuarangi, waihoki ki ngā tukunga iho whānui e pā ana ki te ohaoha me te taiao, tae atu ki ngā whakarerekētanga ki te whakamahi hua o te whenua, te whai mahi, te kounga wai, te kanorau koiora me ngā uara ahurea, tākaro anō hoki.

Kāore he whakaohorere, mā ngā ara e rua e whakawhānui ai te takiwā ngahere. Engari ko te whānuitanga he tino rerekē, kāore e pērā te whakarerekē whakamahi whenua pōturi ki te ara rerekē, he pai ake ngā tukunga iho ki te hapori me te ohaoha.

I muri i ēnei kitenga, ka whakawhanake te upoko i ētahi whakaaro tīmatanga mō te tikanga o te ara ‘pūtake horanuku’ ki te whakahaere āhuarangi me ētahi atu wero taiao mō ngā ahumahi pūtake whenua me ngā hapori taiwhenua. Mā tēnei ara ka kitea he mea tua atu i te wāhi hei whakaputu waro te horanuku. Engari, ka tirohia te horanuku hei wāhi e whakaratoa te maha o ngā ratonga ā-taiao, ā-pāpori, ā-ohaoha anō hoki me te hononga o aua ratonga.

Kia tika ai tēnei ara me whakakotahi i ngā mea katoa e mōhio ana tātou mō ngā hātepe taiao ki te āwhata horanuku mai i raro, ki ngā mātauranga pakiaka kararehe. Waihoki, me pīrangi ngā kaipupuri whenua me ngā hapori ki te mau i ngā tūraru maha e whakapiritia ana ki ngā ritenga whakamahi whenua.

Ko ngā whakaaro pēnei ka noho pēnei – he whakaaro hōhonu kāore e taea te whakamahi. He mea waimārie, ko te whakamahi i ngā utu whakaputa hei whakapoapoa i ngā whakarerekētanga ki te whakamahi whenua me te whakahaere whenua e homai nei i te mātāpuna moni whiwhi ki te tautoko i te whakawhitinga. Ko tētahi wāhanga o te moni whiwhi mai i ngā putanga koiora, ka whakahokia ki ngā horanuku me ngā hapori i puta ai aua moni. Ko taua moni whiwhi ka tautoko ai i te whakatō rākau me ngā mahi tūhono i hoahoa ki te whakaheke i ngā tūraru āhuarangi me te whakatōhenehene ā-taiao, ā-ohaoha anō hoki.

Ētahi whakataunga tīmatanga

Ko tētahi take o tēnei pūrongo i tuhia ki te wero i te kaupapa ko te ara hou mō te whakaaro whakarite whāinga me te pūrongo āhuarangi kāore e taea te whakahē. Tērā ētahi ara rerekē hei whakaarotanga mō te take, ka whakauru i ngā utu rerekē, ā, ka whakaputa i ngā tūraru rerekē. Me reri ngā kaihanga kaupapa here ki te whakamātau i ngā ara rerekē , kaua e whakaae me te kore tautohe 'kāore he ara rerekē'. He ara rerekē i nga wā katoa.[4]

Ki taku nei titiro, he pai te whakakore i te āheinga ki ngā whakatotohu ngahere hei tohu i tō tātou kore mōhio ki te whakahaere i ngā tūraru o te whakapūmau i ngā whakatotohu mō ake tonu atu mō ngā angawā e hiahiatia ana kia whakarite te whakamahana karioi o ngā putanga hauhā. He mea tūtohu tēnei nā te mea ko te hauhā te tino take o te whakapiki paemahana a-ao, kāore e taea te whakaroa ake i te tino mahi āhuarangi ki te whakamahi i ngā putanga hauhā mātātoka katoa.

He tino tūranga tō te ngaherehere. He pai ake te whakamahi i te ngahere hei karo i ngā putanga koiora nā te mea ko ngā ngahere me ngā pāmu he wāhanga nō te hurihanga koiora tere me te hurihanga hauota, ā, ko te roanga o te whakaaweawe whakamahana e ōrite ana ki te roanga o ngā painga o ngā rākau. Ā, he painga anō tō te ngaherehere.

Ka pātaihia te Pāremata ki te hanga ture mō tētahi, ētahi rānei, whāinga karioi. Me pēnei, me whakaata taua whāinga i te whakaeaea o te Whakaaetanga o Pārihi. Ko te tikanga ki te horopaki taiwhenua, me whakarite. Ahakoa he aha te whāinga me pūmau tonu haere ake nei. Kua tūtohu au me whakature i ngā whāinga whakamutunga a muri ake o te āta tirohanga e te Kōmihana Āhuarangi hou. Mā te tūtohu o te kōmihana e tatutoko ai i te āheinga kia tautokohia ai te whāinga, ngā whāinga rānei, e ngā pāti katoa o te whare.

Māku e kī atu ko te ara rerekē i whakawhanakehia ki te pūrongo nei e whakaāhei ai i te whāinga putanga mātātoka whakaheke kore katoa e whakaritea mō te hauhā mātātoka hei te tuarua o te rautau, me te nekehanga mārama ki tēnei whāinga kia tae ki te 2050.

Kei whakamatakuhia te tāngata e tēnei. I ngā 50 tau kua pahure ake nei, kua huri ngā motokā mai i ngā waka tawhito kaiapo ki te penehini, ki ngā waka hiko e haere ana mō te 500 kiromita ki te whakahiko kotahi. Kua kitea e tātou te piki o te hiko nō te rā me te hau ki te nui kāore i wawatahia i te haurua rautau kua pahure ake. Ehara i te wawata noa ki te whakaaro mō te wāheke me te kore whakaputa kora mātātoka.

Heoi anō, mō te mewaro koiora me te hauota-rua ōkai, ka whakaritea te whāinga rerekē. Hei kaiārahai ahuwhenua, ko te mahi a Aotearoa ki te whakamauru i ngā putanga koiora ka kōrerotia ā-ao. Ehara i te mea me kore te taumata whāinga mō ngā putanga, engari me tūhono ki te tukunga iho paemaha e taea te parahau ā-pūtaio,

[4] He nui rawa atu ngā moni whiwhi. Hei tauira, ko te whakatauira i te ara rerekē ki te takiwā awa o Hurunui mai i tēnei wā tae atu ki 2050, e mea ana ka tae pea ki te $640 miriona e wātea ana ki te takiwā awa nei, mēnā i whakahokia ēnei pūtea ki tēnei horanuku.

ā, tētahi e whakapae ai tātou me whai ētahi atu motu. Ahakoa he aha te taumata i whakaritea mō ngā putanga koiora, ko ngā whakatotohu ngahere he mātāpuna tika mō te whakamauru.

Ko te ara pērā ka āta whakamārama i pūtake me ngā whakaaweawe ohaoha me ngā whakaaweawe paemahana e whakaarohia ana, he mea kāore i kitea i raro i te ara kore whakamau mātāpuna me ngā whakatotohu. Me kī pēnei, me whakatau ngā kaihanga kaupapa here mēnā e hiahia ana rātou kia toa ki te kaute kore whakamau i 2050 (tētahi atu tau whāinga rānei) mā te whakaputu i te waro ki ngā ngahere ki ngā takiwā maha o Aotearoa; ko te ū rānei ki te whakaheke i ngā putanga mātātoka me te tuku i te kōrero mārama mō te whakaheke tika o ngā putanga koiora.

Ka puta pea te ara onāianei te tūraru pēnei, ka tutuki tātou i te putanga whakamau kore me ngā putanga mātātoka katoa e haere tonu ana ki te haurua o te taumata onāianei, ā, ka hiahia tonu ki te wā me te whenua ki te karo i te toenga tae atu ki te wāhanga tuarua o te rautau.

Kāore he ara hei karo i ngā putanga mātātoka kore nā te mea ki te whakamutu i te panoni āhuarangi, kua whakakaha rawa, ki *tētahi* taumata paemahana me kaua rawa ētahi atu waro mātātoka e whakaputa ki te kōhauhau. Ko te whakaputu i te para mai i ngā putanga mātātoka ki ngā whakatotohu ngahere he whakaroa noa iho i tērā e haere mai ana.

I te moatatanga o ngā whiriwhiringa he ara e taea ai te parahau – ahakoa i taua wā kua kōrerotia te whakahē mēnā ko te wā ki utua ka whakamahia tikatia. Kua tika ngā kaiwhakahē.

Kua kore ngā tau i waenganui i whakamahia kia tautohetohe mō te whakaiti waro i te ikiiki me te ahumahi, kua whakanui a Aotearoa i tana hauhā mātātoka katoa mā te 35 paihēneti i te tau 1990. Waihoki, ko te ngaronga whakamau o te 50,000 heketea o ngā ngahere whakatō i kitea i waenganui i te pāhitanga o te Ture Whakautu Panoni Āhuarangi i te tau 2002, me te mutunga o te wā titikaha o te Tikanga o Kyoto i 2012. Ka tino mōhio tātou ‘he rerekē tēnei wā’?

Me pānui me te kaute a-ao a Aotearoa mō ana putanga mā te ine e whakaaetia kia hakamahia i taua wā. Engari kei a Aotearoa tana ara ki te whakaiti i ngā putanga. Ka pau te 25 tau e taupatupatu ana me pēhea e ahu whakamua, tērā te hiahia whānui kia mahi i tētahi mahi.

Engari ko te āhua o taua ‘mea’ me tika i runga i ngā tūraru, me tuku ki te angawā e taea ai te whakahaere, ā, me whakaaro i te whakaritenga putanga motuhake o te motu. Me hanga ngā whāinga me ngā kaupapa here i runga i te pūtaiao me te ohaoha. Ka whakamātau tēnei pūrongo ki tuku māramatanga ki tēnā taitara, ki tēnā taitara. Engari, kāore e tū hei rīwhi mō te hiahia ki ngā whakataunga matatika, ki ngā whakataunga tōrangapū.

Ko te tukunga iho o taku rangahau roa e toru aku tūtohu mō te Pāremata i te wā ka whakaarohia te Pire Waro Kore:

- Whakaritea ngā whāinga e rua mō te wāhanga tuarua o te rautau: he whāinga kore putanga mātātoka katoa ka whakaturehia hei wāhanga nō te whakatūnga o te Kōmihana Āhuarangi hou; me te whāinga whakaheke mō ngā putanga koiora e tūtohua e te Kōmihana Āhuarangi hou, kātahi ka whakaturehia. He rā i muri i te 2050 ka tautoko tonu i te Whakaaetanga o Pārihi, ā, me kaua e whakahēngia mēnā he angawā pono e taea te tutuki hei whakaaweawe i te whakawhitinga nui o te ohaoha.
- Whakaaetia te āheinga ki ngā whakatotohu ngahere hei karo i ngā putanga koiora anake, ki te pūtake e tūtohua e te Kōmihana Āhuarangi.
- Hangaia ngā taputapu e hiahiatia ana ki te whakahaere i ngā mātāpuna koiora me ngā whakatotohu i roto i te horopaki o te ara pūtake horanuka e tiro ai ki te wai, ki te oneone me ngā whāinga koiora.

Ko tikanga o te ara horanuka ko te whakapoapoa i ngā kaiwhiwhi whenua me ngā hapori ki te mahi. Ko ngā taputapu pūrongo e hiahiatia ana he mea i tua atu i ngā taputapu me ngā waeture. Heoi anō, ko te whakamahi o ngā moni whiwhi utu putanga he taputapu kaha ki te tautoko i ngā kaiwhakamahi whenua kia whakamahi i ngā rerekētanga nunui ki ngā horanuku e noho ana rātou.

Ka mutu, ka akiaki au i ngā kaihanga kaupapa here ki te āta titiro ki te wā karioi i te whakaritenga o ēnei whāinga. Tērā ngā kōrero tau me ngā hoko atu, hoko mai, i roto i ngā tahua putanga moata i te tīmatanga o te whakawhitinga. Kāore e kore, tērā ngā taupatupatu mō te whakakaha me te āhua ā-mahi. Engari kaua ngā whāinga karioi e noho mau herehere ki ēnei taupatupatu.

Kāore taku pōhēhē mō te taumaha o te wero mā ngā kaihanga kaupapa here. Ko te tino whakamātau, me te pono, ki te tīmata i te huringa e hiahiatia ana e te panoni āhuarangi ka tautokohia e au. Ko taku moemoeā ka āwhina tēnei pūrongo i ngā tāngata maha ki te āta whakaaro he aha te tikanga o te huringa ki te taumata o te horanuka me ngā tūraru kia whakahaeretia ai.

Simon Upton

Parliamentary Commissioner for the Environment

How we have shaped our landscape

Key points

- New Zealand has a long history of land use change dating back to Māori settlement and continuing through the arrival of Europeans to the landscapes of today.
- The clearance of Aotearoa New Zealand's forests shifted huge volumes of carbon from stable forest stores into the atmosphere and commenced our intervention in the carbon cycle.
- Through the introduction of exotic grasses, nitrogen-fixing plants, and ruminant farm animals that generate methane and nitrogenous waste, we have further altered the natural carbon cycle and intervened in the nitrogen cycle too.
- While some of the carbon emitted from land use change has been sequestered back into the landscape by plantation forests, regenerating forest and scrub, much more of it remains in the atmosphere.
- Climate mitigation will drive changes across New Zealand's landscapes once again. Learning from previous transformations will require a closer interest in the potential for change to our landscapes from the outset of any new policies.

The story of Aotearoa New Zealand's landscapes and its ownership is one of dramatic transformations over the last millennium. Three major, human-driven changes have occurred: deforestation, pastoralisation and intensification, and these changes have had significant and widespread consequences for the physical and biological environment.

To date, much attention has focused on the adverse consequences of these transformations for indigenous species, and the state and health of our soils, waterways and coasts. Unenviably, New Zealand has some of the highest levels of endangered plants and animals and highest rates of soil erosion in the world, as well as serious problems with water quality in parts of the country. These problems are well acknowledged, and are the focus of much effort by Government, communities and individuals to tackle them.

However, the widespread transformations to the way we use our landscapes have also resulted in large increases in emissions of the three main anthropogenic greenhouse gases (carbon dioxide, methane and nitrous oxide), and changes in where and how carbon is stored in the landscape. As a nation, we are far less advanced in our understanding and efforts to deal with the consequences of these actions.

When you look at almost any New Zealand landscape outside the barren alpine zone, you are looking at stored carbon. If you are looking at an ancient podocarp forest in one of our national parks, you are looking at a reservoir of carbon, some of which has been there for many centuries.

If you are looking at lush Waikato pasture, you are looking at a large amount of soil carbon, as well as what there is to be found in the grass. And if you are looking at one of our radiata pine plantation forests you are looking at a huge volume of carbon that has been taken out of the atmosphere.[1]

In some cases, the same land will have cycled through several phases – for example, from native forests and wetlands transitioning to pasture (in the process losing a huge volume of carbon to the atmosphere), and then into plantation forests or scrub (when some of that carbon is drawn down again).

This is the biological carbon cycle in action. It is the basis of life on this planet, and we have intervened in it massively and continue to do so.

In reshaping our landscapes, we have shifted a large amount of carbon from the land to the atmosphere. In New Zealand, from an estimated standing stock of around 7.8 gigatonnes of carbon before human settlement, we have liberated around 3.3 gigatonnes.[2] It is our biggest single contribution to changing the Earth's climate

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[1] In this report, unless specified otherwise, 'plantation forestry' refers to rotations of the exotic radiata pine *(Pinus radiata)*, the dominant production forestry practice in New Zealand today. 'Native forest' refers to indigenous forests with no intent to harvest. Both types of forest can be considered permanent, in the sense that the land use remains the same. This convention was adopted to refer to the two main forest types that are familiar to New Zealanders, and reduce the need for detailed description each time a forest is referenced. It is acknowledged that alternatives exist.

[2] A gigatonne is one billion (1,000,000,000) tonnes. To give an idea of scale, one gigatonne has been calculated to be equivalent to the mass of all the mammals on Earth, excluding people, or twice the weight of all the people alive on the planet, or three million Boeing 747s.

system. Of what is left, we currently have 0.2 gigatonnes of carbon stored in radiata plantations, 1.5 gigatonnes stored in native forests, 2.6 gigatonnes stored in soil, with the remainder in scrub, grasslands, wetlands and crops.[3]

Up until the 1860s, human interventions in New Zealand's carbon cycle were directed towards meeting the needs of people living on these islands.

From the second half of the nineteenth century New Zealand's landscapes became driven by the demands of an increasingly globalised market for wool, food and timber. Changes to the landscape have reflected the increasing control of soil fertility and the relative price of internationally traded commodities.

Now, in the early twenty-first century, a new force for landscape transformation is starting to make itself felt: the need to respond to climate change. At this stage the signal is largely driven from undertakings made in international negotiations. But as climatic change starts to bite, it will also be driven by a need to cope with physical, environmental, cultural, social and economic factors here at home. If we are to learn from previous transformations, we need to take a closer interest in the potential for change to our landscapes from the outset.

The Government is in the process of developing new climate policies aimed at mitigating our human intervention in the carbon cycle. In doing so it has the potential to change our landscapes as rapidly and profoundly as previous interventions. A fourth phase of landscape transformation lies ahead.

It is important that the potential impact on our landscapes that will be caused by expected land use changes is carefully considered. When it comes to managing landscapes, climate change is not the only consideration. We have also to address concerns for water quality, soil conservation and biodiversity, as well as the viability of rural communities. The full value of landscapes cannot be expressed purely in monetary terms, but needs in addition to be able to embrace people's cultures and their connection to places, their tūrangawaewae.

In many cases, addressing one environmental pressure will help address another, while in other cases there will be trade-offs. For instance, replacing pastoral farming with radiata pine on steep, erodible land will capture carbon and reduce soil erosion. However, during harvest large amounts of erosion can occur, adding sediment and debris to river beds and estuaries.

When it comes to climate policy, New Zealand is navigating uncharted waters. Our country's emissions profile stands out for two reasons. Much of our energy already comes from low-carbon sources. And a large proportion of emissions are biological, a result of the large quantities of food and wood we produce for export. We face difficult policy questions that most countries have not yet needed to turn their minds to.

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[3] These estimates are based on land cover estimates from historic sources and the 2012 Land Cover Database, and carbon stocks from the New Zealand Greenhouse Gas Inventory, and are described in more detail in chapter 3.

This report explores what different ways of dealing with New Zealand's unique emissions profile could mean for the management of our landscapes and the people who live in them. In doing so, it aims to aid discussion on the development of an effective and enduring climate policy. Whatever that policy is, it will simply be the latest phase in a centuries-long tussle with the carbon cycle.

Changes in New Zealand landscapes

Deforestation

Since their arrival over 700 years ago, humans have dramatically changed Aotearoa New Zealand's landscapes.[4] The most visually striking change has been to land cover. Over the course of New Zealand's human history, forests have been burnt and cut down, wetlands drained, and vast areas of grassland pasture established.

Rapid change began with the arrival of Polynesians from the Pacific Islands in the thirteenth century, accelerating with the arrival of the first European ships 500 years later.[5] At the time of the first people arriving, the land was about 80 per cent covered in forest.[6]

Māori viewed the land as a resource for survival as well as a key part of their ancestry. Over time, Māori created links between themselves and the environment, learned how to live here, and developed principles that enabled them to manage resources in a sustainable way.[7] By the time European settlers arrived in the early nineteenth century, a large amount of forest had been cleared and burnt to aid hunting, defend pā, cultivate crops and promote growth of wild food. Huge amounts of stored carbon had been released to the atmosphere.

Today forests cover approximately 30 per cent of New Zealand, 23 per cent of which is native forest.[8]

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[4] Wilmshurst et al., 2008.

[5] Ministry for Culture and Heritage, 2018.

[6] Masters et al., 1957. (Cited in McGlone, 1989); Stevens et al., 2007, p.65; Wilmshurst, 2012.

[7] "Māori views of the world are based on the proposition that the environment is an interacting network of related elements, each having a relationship to the others and to earlier common origins. The personification of the Earth and the sky as the parents Rangi and Papa underlines that point. Not only is a distinctly human dilemma presented as an explanation for creation, but by comparing the features of the environment to a family, a model is proposed for examining the connections and interdependencies which occur between forests and oceans, fish and fowl, the rivers and the soil and between people and the elements. ... Māori gave some priority to the principles which underlie sutainable management and the needs of future generations". Durie, 1998, pp.21–22.

[8] Forest is 23.5% indigenous and 7.2% exotic (Landcare Research New Zealand).

Source: Ref: 1/2-000492-G. Alexander Turnbull Library, Wellington, New Zealand. / records/22506871

Figure 1.1. Atkinson's Bush, Titirangi, early 1900s. While vast tracts of forest were cleared for timber and to make way for pasture, towns and settlements up and down the country were also cut from the bush. In many urban areas, none of the original forest remains, although in some places, including Atkinson's Bush, pockets of forest still exist as reminders of the original landscape.

The rise of pastoral farming and plantation forests

Most early European settlers came from countries dominated by pastoral agriculture, and they set about taming the wild country and converting New Zealand's landscapes into 'an English farm in the Pacific'.[9] They accelerated land clearing to suit the pasture grasses and nitrogen-fixing clovers they brought with them, and established grazing land for ruminant animals such as sheep, cows and goats.

The very first sheep were brought to New Zealand in 1773, and following European settlement quickly became the most common livestock in pastoral landscapes, which they remain to this day.[10]

As sheep numbers grew, 'good' land with pasture became scarce and farmers worked hard to turn more marginal land into farmland. Large areas of native forest were burned so sheep could graze on the regrowth or grass seed could be sown amid the ashes. In more fertile areas, pasture was established relatively easily. But elsewhere it meant battling resilient native scrub.

Fertilisation of the land began in the late 1800s, with waste from meat processing sometimes applied to fields. Phosphate fertilisers, nitrogen-fixing herbs and improved breeding techniques began to be used in the 1920s, allowing pasture grasses to be established on poorer soils.

As settlers transformed New Zealand's landscapes, a large amount of carbon that had been locked up in leaves, limbs, roots and soils was released into the atmosphere in the form of carbon dioxide. The establishment of pastures, draining of wetlands and introduction of ruminants began our intervention in the nitrogen cycle.

Settlers were not the only farmers. Māori embraced new techniques to increase production from their lands during the 1800s. Traditional cropping techniques, such as shifting cultivation areas every few years as fertility declined, were modified with new tools and cropping species, or replaced by European farming systems to generate crops for profit rather than subsistence. Wheat, kūmara and potatoes were the main crops grown by Māori, and after the 1880s there was further experimentation with exotic crops like tobacco, hops and mulberry trees.[11]

Around the same time, pasture farming for sheep, cattle and pigs also increased. In 1886, over 100,000 sheep, and 40,000 cattle were farmed by Māori in tribal collectives and as individual land owners. Farming was and still is a thriving business for Māori.[12] However, the loss of land by Māori as a result of European settlement unquestionably assisted with the change from mostly indigenous vegetation to current landscapes.[13]

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[9] Quote by Harold Macmillan, British Prime Minister 1957–1963. Cited in Holland and Kelly, 2012.

[10] StatsNZ, 2016a.

[11] Hargreaves, 1960.

[12] Hargreaves, 1960.

[13] Although the word ownership was used to illustrate the relationship between Māori and land, the connection was based on relationship with the land as discussed above. Land was 'owned' collectively by the whānau, hapū or iwi and determined by ancestral rights (Kingi, 2008).

By the end of the century, New Zealand was exporting wool, meat and butter to the United Kingdom. The development of refrigeration technology in 1882 allowed New Zealand to ship chilled meat around the globe.[14]

Changes to our landscapes began to be driven by forces far from our shores. Small and medium-sized pastoral farms were flourishing and sheep numbers grew steadily. By 1960, New Zealand was home to around 47 million sheep, as well as three million beef cattle and three million dairy cattle.

Source: Auckland War Memorial Museum Tāmaki Paenga Hira

Figure 1.2. Mustering, 1930s. The first half of the twentieth century saw large-scale expansion of the sheep industry in New Zealand. The development of fertilisers and aerial top dressing techniques helped open up large areas of country. Often these areas proved to be too remote or difficult to farm and they were subsequently turned to plantation forestry or simply left to revert to scrub.

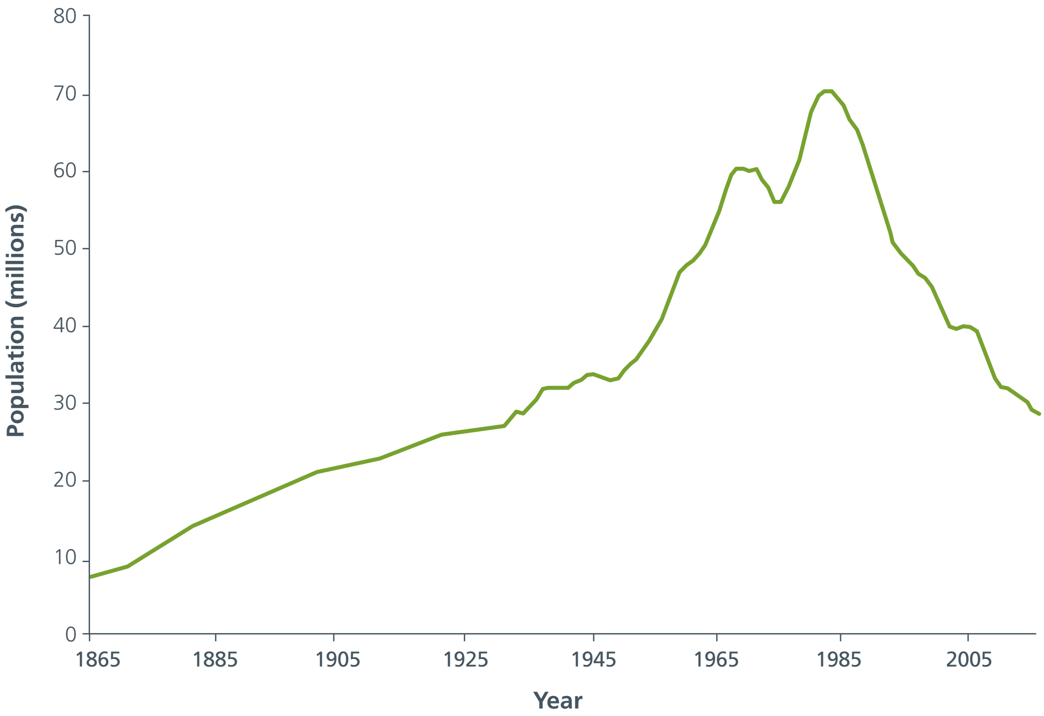
Wool prices began to fall in the 1960s, due in part to the growing use of synthetic fibres for textiles. In the early 1970s, the first international oil shock increased transportation costs and the United Kingdom's entry into the European Economic Community compromised New Zealand's access to the British market. This led to a decline in sheep numbers between the late-1960s and mid-1970s.

[14]The first shipment of frozen lamb was sent to London from Port Chalmers in 1882 (StatsNZ, 2016a).

Following the introduction of subsidies and production incentives soon after, this trend was reversed and sheep numbers peaked at just over 70 million in 1982.[15]

Agricultural subsidies were phased out in 1984 and sheep numbers began a steady decline that still continues. By 2016, sheep numbers had fallen from their peak by more than half, to about 27 million. Natural disturbances have also taken their toll on sheep numbers. Droughts in the 1990s were particularly devastating.[16]

Figures 1.3 and 1.4 show historic trends in the populations of sheep, cattle and deer in New Zealand.

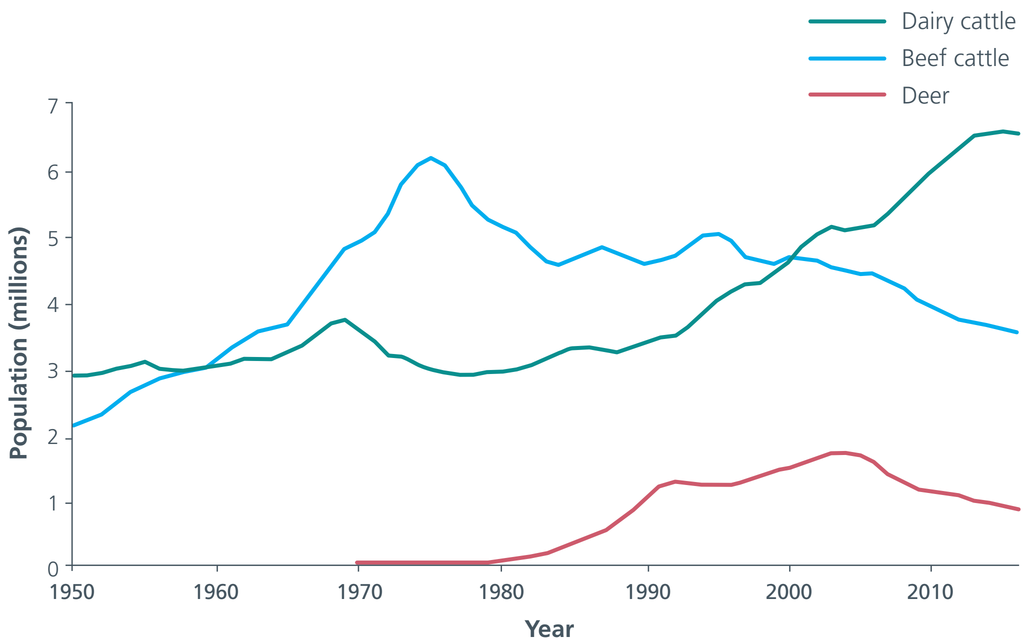


Source: Data sourced from Ausseil et al., 2013, with updates from StatsNZ, 2016b

Figure 1.3. Population of sheep in New Zealand, 1865–2015.

[15] Stringleman and Peden, 2015.

[16] Nightingale, 2008.



Source: Data sourced from Ausseil et al., 2013, with updates from StatsNZ, 2016b

Figure 1.4. Population of cattle and deer in New Zealand, 1950–2015.

As the importance of pastoral agriculture increased in New Zealand throughout the nineteenth century, and as more land was cleared for agriculture and infrastructure, concern about the state of New Zealand's native forests also grew. This concern led to a growing interest in protecting those native forests that remained, but also in planting introduced species for timber.[17]

Before 1840, native timber, especially kauri, was harvested by Māori and sold to European traders. Between 1840 and 1920 however, that timber trade declined due to Government intervention.

By around 1900, more than 60 introduced tree species made up about 5,000 hectares of planted forest in New Zealand. The most common plantation species at that time were eucalypts and larch.[18]

In 1913, a Royal Commission on Forestry was formed to report on whether existing nurseries and plantations were sufficient to meet future demand for timber. A key conclusion of the commission – and one that had profound consequences for our landscapes – was that native species "cannot regenerate sufficiently quickly to allow them to be kept as permanent forests yielding a succession of crops", and

[17] Roche, 2005.

[18] Kininmonth, 1997; Parliamentary Papers, 1909.

recommended extensive planting of exotic forests.[19] A number of species were trialled, including radiata pine, which rapidly became the most commonly planted species.[20]

The first peak in planting took place in the 1920s and 1930s,[21] when about 300,000 hectares of new forest were established, with planting rates reaching as high as 40,000 hectares per year.

A second, longer and larger boom started in the 1950s.[22] From 1965, almost 900,000 hectares of radiata pine plantation forest were established in quarter of a century, with planting rates reaching over 50,000 hectares per year (figure 1.5).

By the 1950s and 1960s, tracts of Māori land were being utilised for plantation forestry predominantly through forestry leases with the Crown, private companies and Māori land owners. The settlement of breaches by the Crown of its obligations under the Treaty of Waitangi led to the transfer of land back to Māori. Most historical claims were land based and as a means of redress, the Crown offered state-owned forest assets.

The Waikato-Tainui settlement in 1995, for example, transferred 47,600 acres of Crown land back to Tainui. Two forests, Maramarua and Onewhero, comprising 6,712 hectares, were given back. If all former state-owned forest assets passed to Māori through Treaty of Waitangi settlements, Maori could collectively end up owning 41 per cent of all currently planted exotic forestry.[23]

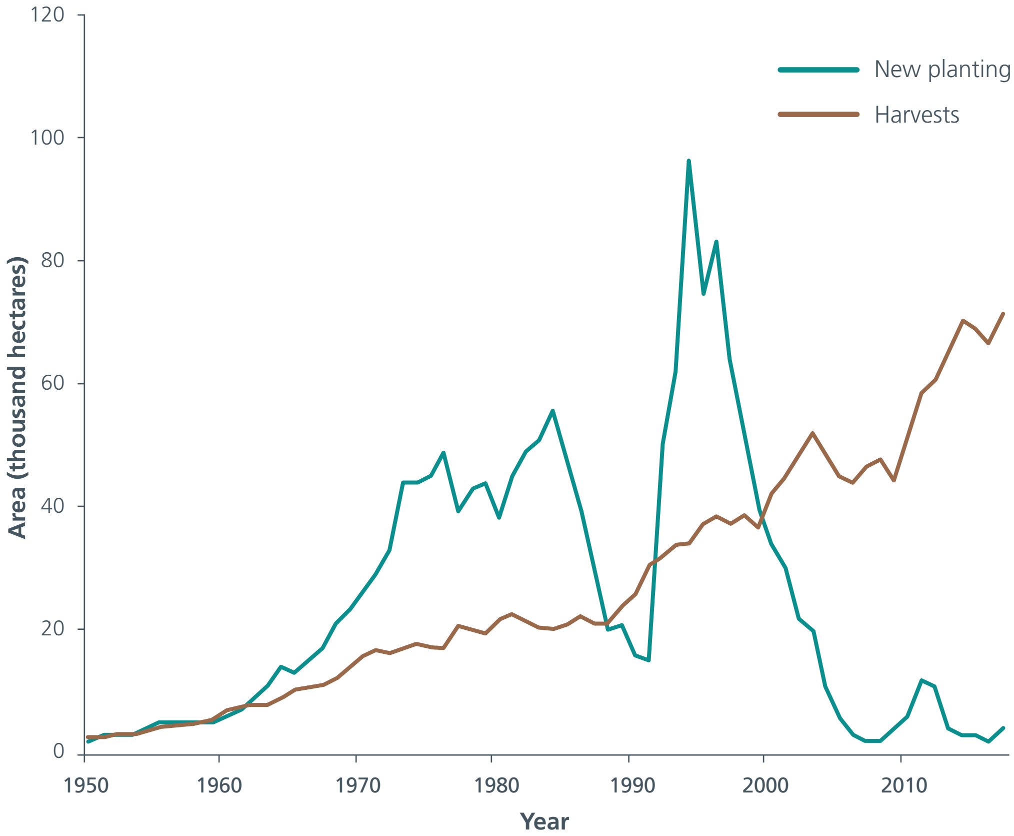
[19] Hegan, 1993. In 1913, A.H. Cockayne noted that buildings in Canterbury built with radiata timber "are still standing, and the timber…is in an excellent state of preservation".

[20] T.W. Adams of Canterbury, a tree enthusiast who trialled more than 200 different species on his land, said of radiata pine that it "has no equal for producing a cheap timber of fair quality" (Kininmonth, 1997, p.13).

[21] Mead, 2013, p.7.

[22] A genetic research programme to select fast growing trees of high quality began in the 1950s. The first 'improved' trees were planted out in the 1970s. For this reason, most of the radiata pines in our plantation forests today are very genetically similar. (Roche, 2008).

[23] Land that is customarily owned today consists of Māori land (administered under Te Ture Whenua Act 1993) and land that was given back as a form of redress through the Waitangi Tribunal process. In 2000, Māori land that was in plantation forestry totalled 238,000 hectares, which made up 14% of the total area of New Zealand's planted forests. In 2007, Māori owned 400,000 hectares of indigenous forest, which is 6% of the total indigenous forest in New Zealand (Miller et al., 2007).



Source: Ministry for Primary Industries, 2017a and Te Uru Rākau, 2018a

Figure 1.5. The area of new and harvested plantation forest across New Zealand.

The most recent boom began in the 1990s. The rate of planting was higher than any previously, reaching almost 100,000 hectares per year. But this boom was shorter, ending by the mid-2000s, by which time about 700,000 additional hectares had been established.

Over the years some of these pine forests have been harvested and replanted, while others have been converted to other uses, including pasture for dairy. All told, total plantation forest area peaked at just over 1.8 million hectares in 2003 and has since fallen to 1.7 million hectares.

In parallel, timber production has grown steadily to reach an all-time high of 71,000 harvested hectares in 2017. Much of the large amount of plantation forest planted in the 1990s is now reaching harvesting age, so the area about to be harvested, and hence the amount of carbon removed from it, is expected to rise considerably over the next decade or so.

Intensification and diversification

The availability and use of nitrogen fertilisers increased significantly following the construction of the Kapuni urea plant in Taranaki in 1982, as part of the large, energy-intensive project based on exploiting gas from the Maui field. Improving pasture productivity saw rural land prices begin to rise through the 1990s, pushing farmers to secure greater returns from the land, and driving New Zealand through a third phase of intensification and diversification of its landscapes.

As a result, the productivity and efficiency of New Zealand's agriculture sector increased considerably. While sheep numbers halved between 1990 and 2016, the amount of meat produced from them today has only fallen by about a sixth.[24] Dairy cow numbers have almost doubled, while the amount of milk produced has nearly tripled.

This more efficient agricultural production has led to lower biological emissions per kilogram of meat and per litre of milk – a lower 'emissions intensity'. Emissions intensity in New Zealand's agriculture sector has fallen by about one per cent each year since 1990 and is among the most efficient in the world,[25] although gross emissions have increased by 10 per cent over the same time frame.[26]

The number and type of cattle farmed has changed dramatically over the last few decades. In 1975, 68 per cent were beef cattle and 32 per cent were dairy cattle. Since then beef cattle numbers have gradually declined, while intensive dairy farming has become more profitable. By 2016, while there were only over a million more cattle than in 1975, the split between beef and dairy had roughly flipped: 35 per cent were beef cattle and 65 per cent were dairy.[27]

The agriculture sector has also diversified since the 1980s, with deer, goats, horticulture and agroforestry becoming more common.[28]

Towards the next great landscape transformation?

Today about half of New Zealand, or over 10 million hectares, is covered in pasture. Almost all of this land is grazed by ruminant livestock such as sheep and cows, which emit biological methane and nitrous oxide.

Most anthropogenic biological methane comes from microbial activity in the stomachs of ruminant animals grazing on our pastures. Most of our nitrous oxide stems from microbes acting on urine and dung from ruminants, as well as increased nitrogen fertiliser applications. Compared to most other developed countries, a much larger portion of New Zealand's current greenhouse gas emissions come from these two biological sources.

While a lot of biological carbon has been lost to the atmosphere, large amounts of carbon are still stored in New Zealand's landscapes, most notably in the native forests still covering about 23 per cent of the country.

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[24] StatsNZ, 2016b; FAO, 2018.

[25] Reisinger and Clark, 2015, pp.23–24.

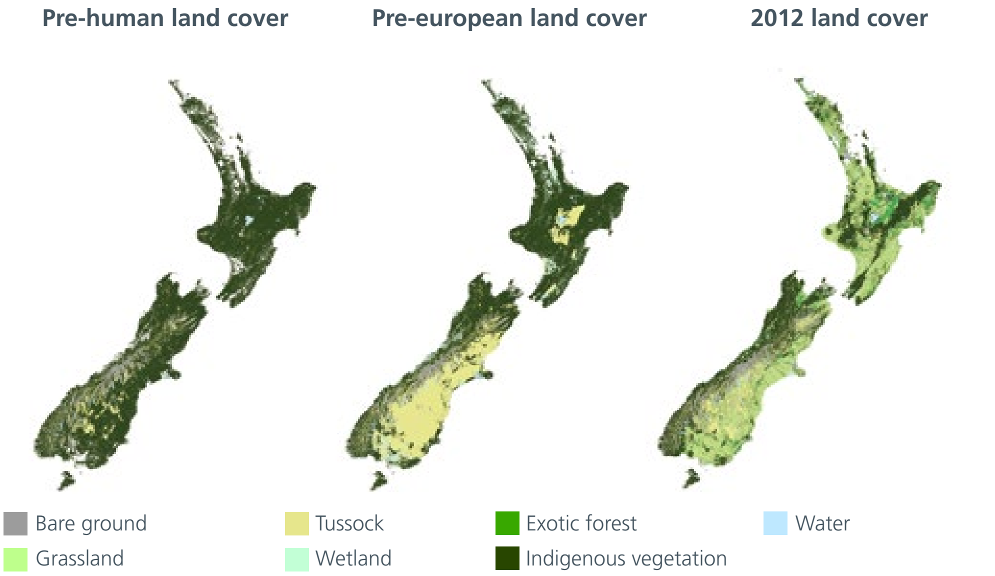
[26] Ministry for the Environment (MFE), 2018a.

[27] StatsNZ, 2016b.

[28] MacLeod and Moller, 2006.

New Zealand's soils also still store a huge amount of carbon, and carbon rich soils support highly productive pastoral, arable and horticultural enterprises. Very marginal land that has been left to regenerate is slowly sequestering some of the carbon released when native forests were cleared.

Figure 1.6 illustrates the changes to land cover that have transformed New Zealand's landscapes since human arrival through to 2012.



Source: Manaaki Whenua - Landcare Research

Figure 1.6. Comparison of land cover in pre-human times, pre-European times and 2012.

This report is being released as the Government works to introduce a Climate Change Bill into Parliament. The indications are that the proposed Act will set up a process to progressively reduce emissions to meet a 2050 emissions reduction target, and that for the first time farmers will be subject to climate policies.

However targets are finally expressed, and whatever policies are developed to achieve them, they are likely to set off a fresh round of land use change and transformation of our landscapes. This is because of New Zealand's unusually high share of biological emissions and its well-established policy of regarding new forest sinks as a key climate change mitigation response.

Any debate about alternative ways forward should have a solid scientific basis, and explore the potential for a wide range of environmental and economic impacts on New Zealand's landscapes. Learning from previous transformations will require a closer interest in the potential for change to our landscapes from the outset of any new policies.

There is now a need for an in-depth conversation about how biological sources and sinks should be treated in the context of New Zealand's overall climate policies.

This report is one contribution to that conversation.

2

Carbon dioxide, methane and nitrous oxide: origins and environmental impacts

Key points

- Rising concentrations of the three main anthropogenic greenhouse gases – carbon dioxide, methane and nitrous oxide – result from human interventions in the global carbon and nitrogen cycles.
- Each gas is different in terms of the strength and duration of the warming it causes. On a tonne-for-tonne basis, carbon dioxide emissions cause weaker warming but have much longer lasting impacts than nitrous oxide or methane emissions.
- The gases and disruptions to the carbon and nitrogen cycles that arise from them also have different impacts on the wider environment. For example, carbon dioxide emissions cause ocean acidification, while nitrous oxide emissions cause ozone depletion and reactive nitrogen is linked to water quality issues.
- These differences suggest that from a scientific perspective, emissions of carbon dioxide, methane and nitrous oxide are not fully substitutable for each other.

Trends in atmospheric concentration

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have their origins in a continual cycling of carbon and nitrogen between the land, oceans and atmosphere on a planetary scale. Human interventions in the carbon and nitrogen cycles have dramatically increased the release of greenhouse gases into the atmosphere and disrupted some of the natural processes that remove them. The net result is that the atmospheric concentration of all three gases is increasing.

The current rate of change in atmospheric carbon dioxide concentration is very rapid. Its atmospheric concentration is now just over 400 parts per million, and climbing at a rate of around 2–3 parts per million per year.[1] These concentrations have increased by around 40 per cent since pre-industrial times, and evidence from ice cores suggests the carbon dioxide concentration is higher now than at any point in the past 800,000 years.[2]

The carbon cycle was stable for about the last 10,000 years, with atmospheric carbon dioxide staying within the range of 260–280 parts per million since the last ice age. This comparative atmospheric stability, varying by just over 20 parts per million, contrasts starkly with the current rapid rate of change.

The main driver of increased concentrations of carbon dioxide and temperature rise today is humans burning fossil fuels – coal, oil and gas extracted from underground.

Methane is over 200 times less abundant in the atmosphere than carbon dioxide. The global atmospheric concentration of methane has increased by around 150 per cent since pre-industrial times, and is currently just under 2 parts per million.[3]

Globally, wetlands contribute 27–32 per cent of methane emissions, and fossil fuel sources are comparable but with more uncertainty at 17–33 per cent. Livestock and landfills add another 14–19 per cent and 11–14 per cent respectively.[4]

Following a plateau between 1999 and 2006, the atmospheric concentration of methane has been rising rapidly. Though several explanations have been proposed, the drivers behind this plateau and subsequent rising trend are not well understood and this remains an active area of scientific research.[5]

Nitrous oxide is over 1,000 times less abundant than carbon dioxide. The atmospheric concentration of nitrous oxide is around 330 parts per billion, about 19 per cent higher than pre-industrial levels.[6] The atmospheric concentration of nitrous oxide has been steadily increasing at a rate of around 0.07–0.11 parts per billion every year in the past decade.

[1] Parts per million, or similarly parts per billion, refer to the comparative concentrations of each gas in the atmosphere, so 400 parts per million of carbon dioxide means that for every million molecules in the atmosphere, 400 are carbon dioxide.

[2] There is also a range of geological evidence showing that the last time concentrations were as high as 400 ppm was about two million years ago (Foster et al., 2017).

[3] 1,867 parts per billion (NOAA Earth System Research Laboratory 2018a). Ice core records show that the atmospheric methane concentration is higher now than at any point during the past 800,000 years (Ciais et al., 2013, p.467).

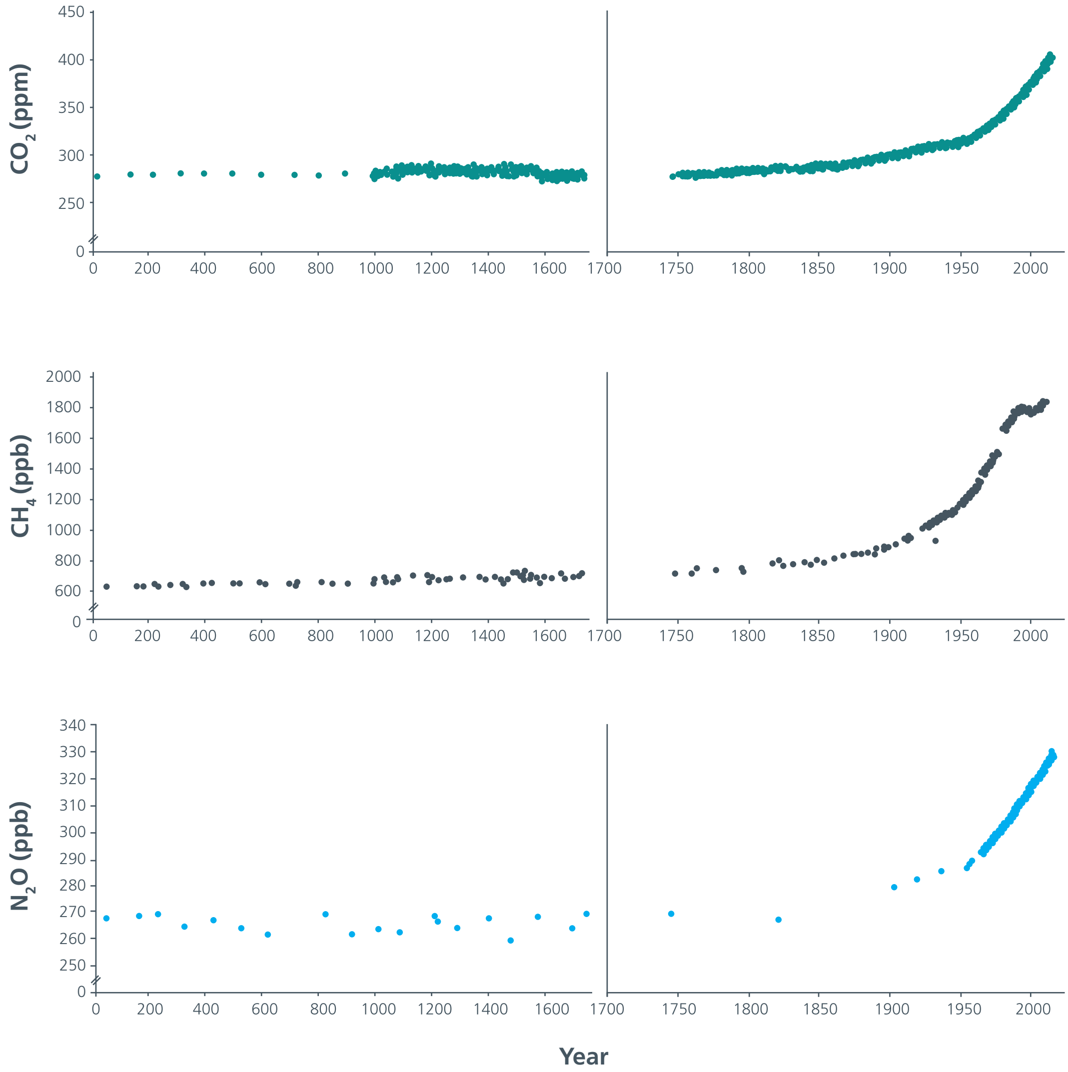
[4] Saunois et al., 2016; Schwietzke et al., 2016.

[5] Nisbet et al., 2019.

[6] NOAA Earth System Research Laboratory, 2018b; Myhre et al., 2013, p.675.

Human activities account for roughly 30–45 per cent of global nitrous oxide emissions. Globally, the main anthropogenic sources of nitrous oxide are the use of nitrogen fertilisers on agricultural soils and fossil fuel combustion.

Figure 2.1 shows global trends in the atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the past 2,000 years.



Source: EPA, 2017

Figure 2.1. Global trends in atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the past 2,000 years.[7]

[7] The concentration of atmospheric carbon dioxide, methane and nitrous oxide in Antarctic ice cores dating back to 800,000 BCE is available at the EPA website. For up to date data see https//www.esrl.noaa.gov/gmd/dv/

The carbon cycle

The Earth contains vast amounts of carbon in various 'pools', which are also known as reservoirs or stocks.[8] Estimates of the size of these pools are highly uncertain, but terrestrial plants are estimated to contain about 450–650 gigatonnes of carbon. Soils contain around three times as much (~1,500–2,400 gigatonnes of carbon, depending on the depth considered). Large amounts of carbon are also held in wetland soils and permafrost.[9]

The total amount of carbon currently in the atmosphere is around 860 gigatonnes of carbon.[10] The oceans contain around ten times more carbon than plants, soils and the atmosphere combined – around 38,000 gigatonnes.

But the size of these pools pales in comparison with the amount of carbon stored in the rocks and deposits within the Earth's crust, or lithosphere. Over 100 million gigatonnes of carbon is estimated to be stored there.[11]

Fossil fuels are a subset of the carbon stored in the Earth's crust. Estimates of this pool size vary widely, but the total volume is thought to be over 8,500 gigatonnes of carbon. But only a fraction, less than 2,000 gigatonnes is considered to be extractable under current economic and operating conditions.[12] For comparison, humans have extracted and burnt about 400 gigatonnes of carbon since pre-industrial times.[13]

Large amounts of carbon are continually flowing and exchanging between these pools. Some of these flows or fluxes are very slow. For example, the natural processes of rock formation and weathering that move carbon between the Earth's crust and other pools typically play out over timescales ranging from thousands to hundreds of millions of years. These flows can be referred to as the slow geological carbon cycle.

Flows of carbon into and out of the biosphere are typically much faster. For example, the photosynthesis and respiration processes that exchange carbon between plants, animals and the atmosphere often play out over time frames of minutes to years. These flows can be referred to as the fast biological carbon cycle.

Slow geological carbon cycle

In the slow geological carbon cycle, the main way carbon is naturally added to the atmosphere is via volcanoes and earthquake-related events. Deep inside the Earth, carbon-rich rocks are melted by the intense heat, producing carbon dioxide. When

[8] Carbon atoms can be part of many different molecules. As carbon cycles around the planet it can exist in many different forms, including gases (such as carbon dioxide and methane), solids (such as cellulose in timber) and dissolved in water in the form of bicarbonate ions. Here 'carbon' refers to the mass of carbon atoms irrespective of the molecule it is part of and the form it is in.

[9] Ciais et al., 2013, p.470.

[10] Based on a monthly global average atmospheric concentration of 405 ppm CO_2 in Sept 2018 and a conversion factor of 2.13 PgC per ppm (NOAA Earth System Research Laboratory, 2019b).

[11] There is a wide range of sizes and stability in the carbon reservoirs. Most of the geological reservoirs are very stable and only recycled into the atmosphere by volcanic activity.

[12] Bruckner et al., 2014, p.525 (Table 7.2).

[13] Boden et al., 2017.

volcanoes are active or there are large earthquakes that rupture the Earth's surface, this carbon dioxide can be vented to the atmosphere at a rate estimated to be around 0.1 gigatonnes of carbon per year.[14,15]

Once carbon dioxide has been added to the atmosphere, there are a number of pathways that it may follow. A proportion will return to the surface in rainfall in the form of carbonic acid, either directly onto oceans, or onto land where it will be washed down rivers into the oceans.[16] The majority of carbon dioxide, however, will return directly to the oceans by dissolving at the surface.

In the ocean, carbon is used in biological processes by marine organisms. Some of the carbon is converted into calcium carbonate by shell-building species.

Source: Eusebius@Commons

Figure 2.2. Mounts Ngāuruhoe and Ruapehu. Being a geologically active country, New Zealand has been an ongoing contributor to natural emissions of carbon dioxide from the slow geological carbon cycle.

A small proportion of the carbon that enters the ocean ends up buried in deep sea sediments. After millions of years of heat and pressure, the sediment is turned into limestone – providing a very long-term storage pool of carbon. Roughly 80 per cent of carbon-containing rock is made this way.[17] Sedimentary carbon-containing rocks are also formed when organic carbon from living organisms is buried in layers of mud on land.

[14]Earth Observatory, 2011; Ciais et al., 2013, p.471.

[15]This geological process accounts for why geothermal power stations emit some carbon dioxide.

[16]This carbonic acid may also cause additional weathering of carbon-rich rocks in streams and rivers as the water flows over them. The dissolved minerals from the rocks are transported by streams and rivers to the ocean.

[17]Earth Observatory, 2011.

Fossil fuels are the product of special sedimentation processes in which organic carbon from the biosphere is converted into coal, oil and gas instead of sedimentary rock.

The amount of carbon dioxide currently being released every year from fossil fuel combustion by humans is about 100 times greater than the amount naturally released by volcanoes.[18] By extracting and burning fossil fuels, humans are removing vast quantities of carbon from the slow geological carbon cycle and injecting it into the atmosphere over a period of time that, in geological terms, is effectively instantaneous.

When carbon dioxide from the slow geological carbon cycle reaches the atmosphere it can become part of the fast biological carbon cycle. Here it can easily interact with terrestrial and marine ecosystems and cycle quickly between the land, oceans and atmosphere. These faster processes are described next, but a key point is that once fossil carbon dioxide is released, a proportion of it stays in the atmosphere for a very long time, elevating atmospheric levels and temperatures.

Fast biological carbon cycle

The fast biological carbon cycle is driven by the sun, which provides the energy for nearly all life on Earth. Plants take carbon dioxide from the atmosphere and use the energy in sunlight to convert it into carbohydrates. This process, termed photosynthesis, takes place in all green plant tissues and is the pathway by which carbon enters the biosphere.

Respiration is the reverse of photosynthesis. Respiration occurs in all living cells and describes the process of converting carbon-containing compounds back into carbon dioxide, releasing chemical energy in the process. In most organisms, respiration is aerobic, that is, oxygen is required to convert the stored carbohydrates back into carbon dioxide.

On balance, a living plant captures more carbon via photosynthesis than it loses via respiration.[19] Typically, a plant itself respires about half the carbon it has fixed in photosynthesis, with the remainder used for the plant's own growth. The carbon retained is incorporated into new plant tissues as the plant grows and could remain there for around a week in flower tissue to several months in leaves, or decades to centuries in wood.[20]

As plants age, leaves and branches fall to the ground where the carbon stored in the litter is taken up by decomposer organisms in the soil, such as worms, microbes and fungi. Some of the carbon is only stored in soil for a short period of time, and is released back to the atmosphere via the respiration of these decomposers. The rest remains in the soil for longer and some of it can become inaccessible to respiring microbial organisms. It can therefore remain in place for very long periods of time until the soil is disturbed.

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[18] Much of the release of these gases from volcanic or earthquake-related events is intermittent in nature. The last IPCC assessment put the long-term average for these "volcanism" CO_2 sources at 0.1 GtC/yr relative to a fossil fuel source over 2000–2009 of 7.8 GtC/yr (Ciais et al., 2013, p.471).

[19] There is a distinct annual pattern in the net gain and losses from plants due to seasonal differences in growth. A large seasonal rise and fall in atmospheric concentrations of carbon dioxide exists – in addition to any long-term trend occurring.

[20] Approximately 50% of the dry weight of plant material is carbon (Magnussen and Reed 2004, Chapter 5).

The mineral composition of soil determines its carbon storage capacity and the longevity of soil carbon. Sandy soils tend to store much less soil carbon than clay-based soils. Soil carbon may also include tough plant tissues or microbial breakdown products that resist decomposition and add to long-term carbon stocks in the soil.

Biological sinks and sources

When the overall rate of photosynthesis of a terrestrial ecosystem like a forest exceeds the rate of respiration, the net effect will be removal of carbon dioxide from the atmosphere. This process is known as sequestration. An ecosystem in this state is often referred to as a sink.

Mature natural forest ecosystems, if whole stands are undisturbed, will eventually reach a more or less stable state.[21] At this point, although each organism is still respiring and photosynthesising, the overall rate of photosynthesis is approximately equal to the overall rate of respiration, so the net exchange of carbon between the atmosphere and biosphere is near zero. An ecosystem in this state is neither a source nor a sink.

When disturbed, an ecosystem can change from being a sink to a source of carbon. Natural disturbances (e.g. fire, flood or landslide) or human-made disturbances (e.g. bulldozing or ploughing) can result in the death of or damage to photosynthesising organisms. If this happens, the amount of carbon being returned to the atmosphere will exceed the amount being sequestered.

To illustrate, a healthy, newly established forest is a strong carbon sink, but as it matures the growth rate slows. If this forest is left indefinitely the rate of new growth over time becomes similar to the rate of decomposition of dead tissue and the mature forest approaches a steady, neutral state. This mature steady-state forest is an important asset in terms of limiting further change. However, if the forest becomes unhealthy so the rate of photosynthesis slows to below the rate of respiration, the forest becomes a source of carbon that is released to the atmosphere.

Over long enough timescales, forest disturbances can be viewed as carbon neutral – in that, while carbon is periodically emitted to the atmosphere as a result of fire, an insect outbreak or a large storm, it will be sequestered again as long as the ecosystem is able to regenerate, returning the land to its former state. But there is still a warming impact from such a disturbance because of the extra heat trapped by the additional carbon temporarily emitted to the atmosphere.

For many thousands of years there was an underlying ecosystem stability at regional and global scales, even when factors such as fire, drought, flood, pests and disease were included. This led to very little biologically driven change to atmospheric concentrations of carbon dioxide (see figure 2.1 above).

[21] There are indications that globally many forests considered to be mature are not yet in this steady state. However, evidence suggests that New Zealand's mature indigenous forests are in a stable, carbon neutral state (Holdaway et al., 2017).

Globally, humans have dramatically altered the fast biological carbon cycle with many climate consequences. In converting our landscapes from forests, scrub and wetlands to farms, cities and ports we have released large amounts of carbon from the biosphere to the atmosphere, while our continued management of these landscapes inhibits its return.[22]

Changing terrestrial ecosystems can alter the climate in many complex ways and at various scales (local, regional and global). For example, burning a forest will not only directly release carbon dioxide to the atmosphere, but will also result in other indirect climate effects and feedbacks (see box 2.1).

Box 2.1. Feedbacks and indirect effects

Feedbacks are processes that result in amplification or reduction of the original effect.

Emitting carbon dioxide has increased atmospheric concentrations considerably and this has resulted in a 'fertilisation effect', promoting increased carbon sequestration in plants and soil. By removing some carbon dioxide from the atmosphere this fertilisation effect has lowered the impact of carbon dioxide emissions on global warming – additional warming would have occurred without this effect.[23] This is an example of a negative climate feedback – reducing the original effect.

Conversely, increased melting of the polar regions due to global warming is releasing carbon dioxide and methane from the land as the permafrost melts, resulting in further warming. This is an example of a positive climate feedback – amplifying the original effect.

Globally, terrestrial ecosystems are currently acting as a carbon sink, removing some of the carbon from the atmosphere each year. But there is concern that climate change will reduce or even reverse the benefit of these currently negative feedbacks. [24]

Oceans also currently absorb large amounts of carbon, and most of the heat trapped by greenhouse gases.[25] This results in lower global air temperatures and atmospheric carbon dioxide concentrations than would otherwise occur. Large oceanic currents act like conveyor belts transporting both carbon and heat to great depths. Any change in these currents could alter the oceans' capacity to operate as sinks.

The topic of climate feedbacks is an active area of research around the world. There is much debate about exactly which feedbacks matter, how they interact with each other and whether or not to include them in climate prediction models. Some known feedbacks are poorly understood, making it difficult to quantify their impact.

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[22] Anthropogenic CO_2 emissions to the atmosphere from all sources, including land use change, were 555 ± 85 PgC (1 PgC = 10^{15} gC) between 1750 and 2011 (Ciais et al., 2013, p.467).

[23] While there is wide agreement that the carbon dioxide fertilisation effect has increased uptake of CO_2 by vegetation globally, estimates of its net effect have varied by a factor of 7 so it is difficult to assess the extent of this effect.

[24] Terrestrial ecosystems absorb approximately 11 Gt less carbon dioxide every year as the result of extreme climate events than they could if the events did not occur. That is equivalent to approximately a third of global CO_2 emissions per year (Max Planck Society, 2013; Ciais et al., 2013, p.467).

[25] "The ocean is the primary heat sink of the global climate system. Since 1971, it has been responsible for storing more than 90% of the excess heat added to the Earth system by anthropogenic greenhouse-gas emissions. Adding this heat to the ocean contributes substantially to sea level rise and affects vital marine ecosystems." (Durack et al., 2018, p.42)

Changing land use from one coloured surface to another can significantly alter the amount of heat absorbed. Dark surfaces absorb more heat than light surfaces. Snow in particular reflects much more heat than bare soil. In the same way but to a much lesser degree, dark pine trees absorb more heat than paler pasture. This is known as the albedo effect. So converting pasture to forest will not reduce warming as much as hoped because of this indirect effect. Limited New Zealand-specific information exists, but one study has estimated that the albedo effect reduces the efficacy of offsetting climate impacts from planting trees in the North Island by as much as 24 per cent.[26]

Trees also release more water into the atmosphere than grasses and promote greater vertical mixing of the air. So converting grassland to forest can have an indirect effect on climate through changes in related heat exchange and the formation of clouds, which may counteract the albedo effect to some extent.

There are concerns that key feedback processes could change in uncertain and unpredictable ways as our climate shifts further into uncharted territory. Global warming could lead to a rapid release or 'tipping point' that would greatly amplify current impacts.

A recent review of the last IPCC assessment report looked at this possible outcome and concluded:

> "In summary, gradual climate change could trigger abrupt changes – with large regional and potentially global impacts – associated with thresholds in the Earth system. The possibility of crossing any of these thresholds increases with each increment of warming. However, although surprises cannot be excluded, there is no compelling evidence that the thresholds discussed here will be crossed this century, or that the IPCC statements need significant amendment."[27]

While planting trees is a well-established action intended to help mitigate climate change and clearly can remove carbon dioxide from the atmosphere, assessing the net global climate benefit of a establishing a new forest, including all of the feedbacks and indirect effects remains a complex area of current research.

Methane sources and sinks

Globally, the main sources of biological methane emissions are flooded soils (such as wetlands, sediments in estuaries and rice paddies), ruminant livestock and landfills.

[26] Kirschbaum et al., 2011, p.3687.

[27] Royal Society, 2017, p.19.

Biological methane from livestock can be thought of as a loop in the fast biological carbon cycle that begins and ends with carbon dioxide in the atmosphere. A simplified version of this loop has three stages:

1. Carbon dioxide is removed from the atmosphere by growing plants and incorporated into plant material as carbohydrates.
2. Plants are consumed by ruminants and the carbohydrates are converted into methane by microorganisms in the rumen.
3. Methane is released into the atmosphere and oxidised back into carbon dioxide.

While this sounds relatively straightforward, in reality the biological methane loop is complicated, and scientific understanding of the complex microbial processes involved remains limited.

What is clear is that this biological methane causes more warming than if the carbon had not gone through the loop and stayed as carbon dioxide. This is because each molecule of methane, as a result of its chemical properties, causes more warming than a molecule of carbon dioxide.

By contrast, the release of fossil methane is not a loop within the fast biological cycle and each new emission not only causes warming from the methane itself, but also adds more carbon dioxide once it breaks down in the atmosphere.

Ruminant livestock are estimated to account for roughly one third of global anthropogenic methane emissions.[28] Ruminants have four stomachs, of which the first and largest is called the rumen. The rumen is a marvel of evolution. It contains billions of microorganisms and enables ruminants to digest foods that other mammals cannot, such as tough plant cell walls. These tough foods are partially fermented in the rumen, and some of the carbohydrates within them are broken down into carbon dioxide and hydrogen gas.

Biological methane is produced by the respiration of specialised microorganisms called methanogens. Methanogens belong to an ancient domain of microorganisms known as archaea. Though they come in different shapes and sizes, all methanogens contain common enzymes that enable them to convert carbon dioxide and hydrogen (and sometimes other substrates) into methane.[29]

The methane produced by methanogens in the rumen cannot be used by the animal, and therefore represents a loss of energy. However, methanogens do benefit the host animal by removing hydrogen from the rumen, which enables other microorganisms involved in fermentation to function optimally.[30]

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[28] Saunois et al., 2016, p.709.

[29] Interestingly, very similar dominant strains of methanogens are found in the rumens of ruminants all over the world (St-Pierre et al., 2015). Some progress has been made sequencing the genomes of these methanogens and while it remains a challenging task, a recently published research into ruminant methanogenic processes led by AgResearch, describes rumen-specific gene encoding (Seshadri et al., 2018). This may open up new options for mitigation of emissions from cows and sheep.

[30] Hook et al., 2010, p.2.

Nearly 90 per cent of the methane emitted by livestock is produced in the rumen and exhaled through the nose and mouth. Sheep have smaller rumens than cattle and therefore produce less methane per animal. A single dairy cow emits around 80 kilograms of methane each year and a sheep around 12 kilograms.[31]

Source: pxhere.com

Figure 2.3. Sheep are a major source of biological methane, through the actions of methane-producing bacteria in the rumen.

Once released into the atmosphere, most methane is broken down through chemical reactions with hydroxyl radicals in the lowest layer of the atmosphere – the troposphere. Hydroxyl radicals are highly reactive chemical compounds consisting of one oxygen atom and one hydrogen atom. They are often referred to as the 'detergent of the atmosphere' due to their ability to oxidise most of the chemicals released into the air.

Hydroxyl radicals are so reactive that each one has a lifetime of less than a second. The oxidation of methane by hydroxyl radicals is a complex chain reaction that produces a variety of products, including carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde (CH_2O), and ozone (O_3).

[31] Ministry for the Environment, 2018a, p.167.

Secondary methane sinks in the atmosphere include chemical reactions with chlorine compounds in the troposphere and photochemical reactions in the stratosphere – the next layer above the troposphere. These various chemical reactions in the atmosphere accounted for around 94 per cent of total atmospheric methane removals between 2003 and 2012.[32]

The remaining six per cent of methane is removed from the atmosphere by microorganisms called methanotrophs that live in porous, well-oxygenated soils. Methanotrophs produce an enzyme called monooxygenase that catalyses the breakdown of methane in the presence of oxygen.[33]

The role of oceans

The oceans store vast amounts of dissolved carbon and currently act as a sink, removing carbon dioxide from the atmosphere. The amount of carbon dioxide taken up by the oceans is similar to the amount sequestered by the terrestrial biosphere, though the rate of uptake by the land is more variable from year to year.[34]

The amount of dissolved carbon in the surface waters of the ocean is linked to the concentration of carbon dioxide in the air. The uptake rate of carbon dioxide by the ocean surface increases as the atmospheric concentration rises and reduces as water warms.

Although atmospheric carbon dioxide is absorbed by surface ocean waters fairly quickly, these surface layers are only a small proportion of the total water column. It takes much longer for dissolved carbon to reach the deeper layers of the oceans. This is because mixing between the surface waters and deeper layers is very slow.

Oceans contain vast amounts of organic carbon within living organisms like algae and marine life. Much like their terrestrial counterparts, marine algae and cyanobacteria use photosynthesis to capture solar energy, absorbing carbon in the form of dissolved bicarbonate. Some of this carbon is lost via respiration, while some is used to form carbon-based structural material such as calcium carbonate shells. The debris and organic waste from these organisms falls to the ocean floor where it becomes sediment and very slowly turns into rock.

Through these processes, the oceans play a vital role in regulating the climate system, and have buffered much of the fossil carbon dioxide humans have emitted to date. As noted above, most of the heat trapped by greenhouse gases so far – about 90 per cent – has also been transferred into the oceans. In this way, the heat trapped in oceans may be considered a better measure of the Earth's current energy imbalance due to greenhouse gases in the atmosphere. Since some of the heat added to the oceans is being moved deep down by currents, the ocean are also currently buffering surface air temperatures too. However, any heat added to the ocean will have other impacts

[32] Saunois et al., 2016, p.705. Global methane sinks were estimated at 548 Tg CH_4 per year in 2003–2012, of which chemical reactions in the atmosphere accounted for 515 Tg CH_4, and soils accounted for 33 Tg CH_4 per year.

[33] Monooxygenase oxidises methane with oxygen to make methanol, which is then broken down further to form carbon dioxide (Strong et al., 2017).

[34] Le Quéré et al., 2018, p.409.

– such as affecting ocean currents and circulation and additional thermal expansion leading to sea level rise.

The ocean has the capacity to absorb and partially buffer increases in atmospheric carbon dioxide for a long time, but the rate at which it will continue to do so depends upon water temperatures and mixing rates, among other factors. Warmer water has less capacity to hold carbon. So if the rate at which cooler water containing less carbon is brought up to the surface slows, then the oceans will absorb carbon dioxide much more slowly.

The nitrogen cycle

Nitrous oxide is produced as part of another natural cycle – the nitrogen cycle. Nitrogen is one of the most abundant elements on Earth and is essential for all life. Yet most nitrogen is locked up in the atmosphere as an unreactive gas (N_2). This is a highly stable form of nitrogen that plants and animals are unable to break down without the assistance of specially adapted nitrogen-fixing bacteria.

Nitrogen fixation is the conversion of atmospheric nitrogen gas into reactive nitrogen compounds such as ammonium (NH_4^+).[35] The main natural fixation processes are lightning and biological fixation by soil bacteria.

Human activities, particularly those related to food production, have greatly increased nitrogen fixation rates. The two main sources of nitrogen fixation in New Zealand are the cultivation of nitrogen-fixing legumes such as white clover, and the production of nitrogen fertilisers.

Nitrogen-fixing legumes contain bacteria in nodules on their roots, which produce an enzyme that catalyses the conversion of atmospheric nitrogen gas into ammonium. The ammonium is then converted into amino acids, which are exported to the plant.

Livestock acquire nitrogen by feeding on plants. Some of this nitrogen is incorporated into the proteins and tissues of the animal. Excess nitrogen is excreted in the form of urea (CH_4N_2O), a highly soluble form of organic nitrogen that is produced in the liver.

Once it enters the soil, the urea from urine and dung is converted into ammonium and nitrate (NO_3^-) by microorganisms. The conversion rates for these processes are highest in warm, moist and well-aerated soils. Both ammonium and nitrate are readily absorbed by plants. However, nitrate is particularly susceptible to leaching into waterbodies, where it can promote runaway growth of plants and algae, altering or degrading aquatic ecosystems, including lakes, rivers and estuaries.

Nitrate is eventually converted back into nitrogen gas by bacteria. This process is known as denitrification. The process consists of a series of steps: nitrate is first reduced to nitrite (NO_2^-), then nitric oxide (NO), then nitrous oxide (N_2O), and finally nitrogen gas (N_2). Thus, nitrous oxide is an intermediate step in the denitrification process, and nitrous oxide emissions are the result of incomplete denitrification.

[35] Reactive nitrogen is a collective term for ammonia (NH_3), ammonium (NH_4^+), nitrate (NO_3^-), nitrogen oxides (NO_x) and other nitrogen species that are chemically reactive and biologically available.

The bulk of the nitrogen in nitrate is released back to the atmosphere as nitrogen gas. The proportion of nitrogen released as nitrous oxide during denitrification depends on soil acidity, moisture levels, temperature, oxygen availability and the degree of soil compaction.[36] In New Zealand, the proportion of nitrogen released as nitrous oxide can range from around 0.3 per cent in well-drained stony soil to around 2.5 per cent in poorly drained soil.[37]

Source: Seamoor

Figure 2.4. Wetlands are a critical part of the nitrogen and carbon cycles. Plants growing in the wetland can capture and incorporate nitrates into their tissues, while, under anaerobic conditions, bacteria may convert nitrates to nitrous oxide that will vent to the atmosphere. Wetland plants will also take up carbon dioxide, but may also release carbon back to the atmosphere as carbon dioxide or methane, depending on the conditions.

More nitrous oxide comes from urine than from dung because the nitrogen in urine is released into the soil quickly, whereas dung takes longer to break down and release its nitrogen. Urine from cows generally releases more nitrous oxide than urine from smaller ruminants because cows deposit large quantities of urine in one place, saturating the soil with a large amount of nitrogen.[38]

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[36] Bhandral et al., 2007.

[37] Manaaki Whenua – Landcare Research, 2019.

[38] These nitrogen 'patches' have been a key focus of New Zealand's agricultural greenhouse gas research programme (NZAGRC, 2018).

In addition to the cultivation of nitrogen-fixing legumes, nitrogen fixation is also achieved through the production of nitrogen fertiliser. Most nitrogen fertiliser is manufactured using the Haber–Bosch process, which converts atmospheric nitrogen to ammonia (NH_3) by reaction with hydrogen at high temperature and pressure in the presence of a catalyst. Ammonia is then converted into urea by reaction with carbon dioxide. Fossil methane from natural gas is used as a feedstock for these processes.[39]

Once nitrogen fertiliser is applied it is swiftly converted to ammonium. Any excess ammonium not absorbed by plants is converted into nitrate in the soil or released into the atmosphere as ammonia gas. This ammonia is then dissolved in atmospheric water vapour and deposited elsewhere by rainfall, or falls directly to the ground as dry deposition.

Nitrous oxide is removed slowly from the atmosphere by chemical reactions involving sunlight and oxygen in the stratosphere, producing atmospheric nitrogen and nitrogen oxides (NO_x). As with methane, the natural rate of removal of nitrous oxide from the atmosphere has been unable to keep up with human-induced emissions, which have increased natural fluxes by about 63 per cent.[40]

The global cycles for carbon and nitrogen described above and their interaction with land use are summarised in box 2.2.

[39] This nitrogen fertiliser is often referred to as 'synthetic'.

[40] Ciais et al., 2013, p.512 (Table 6.9).

Box 2.2. The global carbon and nitrogen cycles and their interaction with land use.

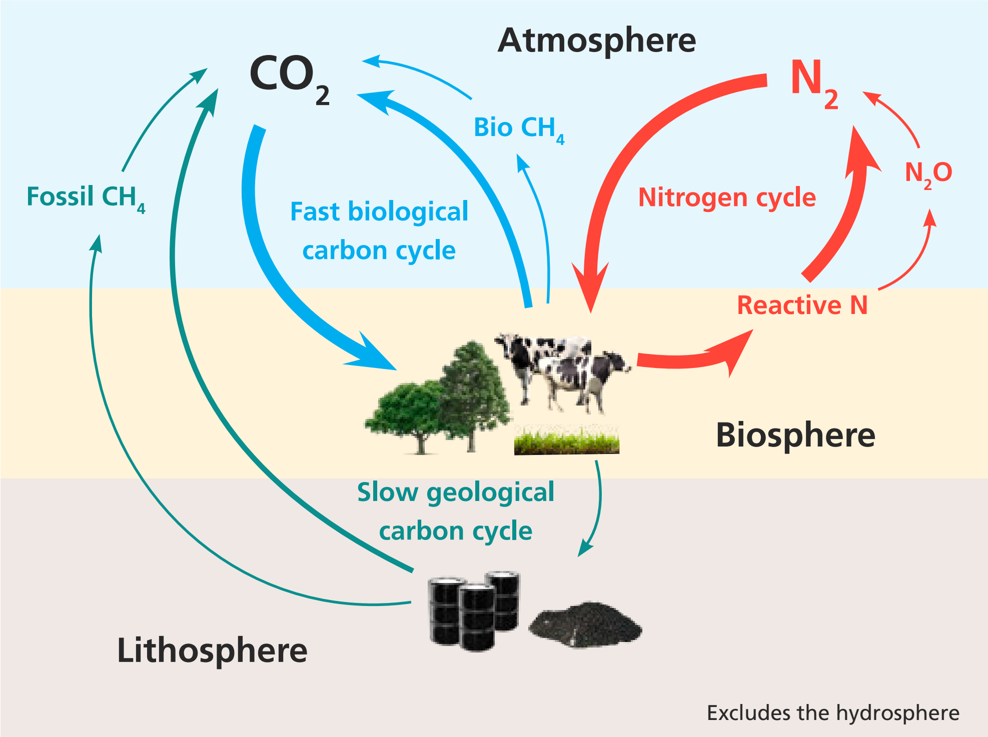

Figure 2.5. The carbon and nitrogen cycles.

- Fossil carbon dioxide, biological methane and sequestration of carbon are parts of the global carbon cycle.
- Fossil fuels are part of the slow geological carbon cycle.
- Carbon dioxide emissions and removals by forests and land use change are part of the fast biological carbon cycle.
- Biological methane is part of a loop within the fast biological carbon cycle.
- Nitrous oxide comes from the nitrogen cycle.
- Combustion of fossil fuels injects carbon from the slow carbon cycle into the fast carbon cycle.
- The nitrogen and carbon cycles are further linked because fossil methane is used as a feedstock in the manufacture of ammonia fertiliser.

Environmental impacts of greenhouse gases

Greenhouse gases have different chemical and physical properties and warm the planet in different ways. The factors determining the type of warming they cause include their lifetimes, the strength of their warming impact, and the by-products from their breakdown in the atmosphere.

In addition to their warming impacts, methane, nitrous oxide and carbon dioxide have other impacts on the environment, such as ocean acidification, stratospheric ozone depletion, and effects on water, air and soil. This underscores why comparing these gases along a single dimension – such as their heat-trapping potential over 100 years – fails to capture the full range of their varied impacts on the environment.

Lifetimes

When greenhouse gases are released into the atmosphere they decay or are absorbed at different rates. The current 'lifetime' of methane is relatively short, at around 12 years. This means that when a tonne of methane is added, the amount left in the atmosphere is reduced by around two thirds roughly every 12 years.[41] The lifetimes of greenhouse gases are not fixed – they depend on the composition of the atmosphere, which is gradually changing over time.

The lifetime of nitrous oxide is longer than methane, but shorter than carbon dioxide. When a tonne of nitrous oxide is released, the amount left is reduced by around two thirds roughly every 120 years.

Carbon dioxide has the longest and most complex lifetime of the three. While some of the released carbon dioxide is quickly absorbed, a small proportion stays in the atmosphere much longer, causing sustained warming for hundreds to thousands of years.

The global temperature impacts of greenhouse gases can continue to linger long after the emissions themselves have decayed.

All greenhouse gas emissions can alter or disrupt the physical, chemical, and biological processes that maintain our environment. A warmer climate causes any carbon dioxide already in the atmosphere to remain there for longer, and more carbon dioxide to be released from oceans and the biosphere. While there is uncertainty regarding the magnitude of these feedbacks, there is clear evidence that carbon cycle feedbacks result in additional warming.[42]

There is significant inertia in the climate system, meaning there is a long lag time between changes in greenhouse gas concentrations and their full impact on global temperature.

[41] In this context, the term 'lifetime' refers to the time taken for the atmospheric concentration to return to 1/e (around 37%) of its initial value following a pulse emission. This is known as the perturbation lifetime and is different to the turnover time, which is the average length of time an individual molecule of gas remains in the atmosphere, which for methane is around 8 years.

[42] Reisinger, 2018.

In the case of methane, a constant flow of emissions results in a constant methane concentration after around 50 years, but its impact on temperature continues to increase for several centuries. Three hundred years after an idealised constant flow of methane emission has started, the warming effect is more than twice as high as it is after 50 years.[43]

Increased warming is also likely to release extra methane, especially that stored in permafrost, while climate-related changes in rainfall appear to be increasing emissions from wetlands.[44] These changes amplify and prolong the warming caused directly by greenhouse gases.

Strength of warming

The strength of the warming caused by a greenhouse gas partly depends on its concentration in the atmosphere and therefore changes over time as the composition of the atmosphere changes. Carbon dioxide is much more abundant and currently warms the Earth more than methane or nitrous oxide. This also means that adding one extra tonne of methane or nitrous oxide has a bigger additional warming effect than adding one extra tonne of carbon dioxide.[45]

Greenhouse gases absorb infrared radiation only at certain parts of the electromagnetic spectrum, and these absorption bands can become partially saturated as the concentration of the gas increases.[46]

This means that adding one tonne of a less abundant greenhouse gas to the atmosphere generally causes more warming than adding one tonne of a more abundant one – though it also depends on the extent to which their infrared absorption bands overlap with those of water vapour and other greenhouse gases.[47]

There are also indirect interactions between different gases in the atmosphere. For example, there is partial overlap in the wavelengths of infrared radiation absorbed by nitrous oxide and methane molecules. This means that as the concentration of nitrous oxide increases, the warming effect of methane decreases, and vice versa.

The warming effect of any single greenhouse gas depends not only on its own concentration at that point in time, but also the background concentrations of the other greenhouse gases and their decay products.

[43] Reisinger, 2018.

[44] Nisbet et al., 2019.

[45] At current concentrations, the warming caused by carbon dioxide is approximately proportional to the logarithm of concentration, while the warming caused by methane and nitrous oxide is approximately proportional to the square root of concentration.

[46] Methane and nitrous oxide are much less abundant in the atmosphere than carbon dioxide. Due to its relatively high concentration, the bands at which carbon dioxide absorbs infrared radiation are partially saturated. Methane and nitrous oxide molecules are less abundant in the atmosphere, so their absorption bands are not saturated.

[47] Some gases have very little effect because their absorption overlaps with that of water vapour.

Warming impact of by-products

The warming caused by methane includes warming from the by-products of methane breakdown in the atmosphere. These by-products account for roughly one third of methane's total heat-trapping capacity (or radiative forcing). The most significant of these by-products are stratospheric water vapour and tropospheric ozone – both powerful greenhouse gases in their own right.

Tropospheric ozone is estimated to account for around 25 per cent of the total heat-trapping capacity of methane. Tropospheric ozone warms the climate and is also detrimental to the health of animals and plants. It should not be confused with the ozone layer in the stratosphere, which helps to protect living things from dangerously high levels of solar radiation.

Stratospheric water vapour accounts for around seven per cent of the total heat-trapping capacity of methane. Methane oxidation accounts for around a third of the total water vapour found in the stratosphere.[48] Methane breakdown also produces water vapour in the troposphere, but this is not counted towards its warming effect because its impact on tropospheric water vapour concentrations is negligible compared to the scale of natural evaporation and precipitation processes.

As noted earlier, methane emissions from fossil fuel extraction include an additional warming effect not caused by biological methane. This is because the carbon in fossil methane comes from coal, oil and gas deposits that have been buried deep underground for millions of years, so additional carbon dioxide is added to the atmosphere when fossil methane oxidises. This additional warming effect from carbon dioxide accounts for around two per cent of the total heat-trapping capacity of fossil methane over 100 years.

Most nitrous oxide is converted to nitrogen gas in the stratosphere. Nitrogen gas is not a greenhouse gas. A small proportion of nitrous oxide is converted to nitrogen oxides (NO_x), which have a cooling effect on the climate. Further, some of this nitrous oxide is converted to ammonia, is deposited back onto the land, which enhances vegetation growth and carbon removal. These processes slightly diminish the warming impact of nitrous oxide, though it remains a very potent greenhouse gas.

Impact on the stratospheric ozone layer

In addition to their climate impacts, carbon dioxide, methane and nitrous oxide have an impact on the stratospheric ozone layer. This layer of ozone filters out some of the ultraviolet radiation coming from the sun. This is important because too much ultraviolet radiation is harmful for most organisms on Earth.[49]

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[48] Institut für Umweltphsik: "[T]he amount of water vapour in the atmosphere is controlled mostly by air temperature, rather than by emissions. For that reason, scientists consider it a feedback agent, rather than a forcing to climate change.", Myhre et al., 2013.

[49] Butler et al. (2016, p.5) point out that too much stratospheric ozone levels may also be undesirable, as low-level exposure to ultraviolet light is required for some ecological functions.

Carbon dioxide and methane increase stratospheric ozone levels. They do this by changing circulation patterns and cooling the upper stratosphere, which slows down the rate of the photochemical reactions that destroy ozone.

Nitrous oxide, on the other hand, depletes stratospheric ozone. Following the successful phase-out of chlorofluorocarbons (CFCs) and other industrial ozone-depleting substances under the Montreal Protocol, nitrous oxide has now become the main driver of stratospheric ozone loss.[50] This is because it produces nitrogen oxides in the stratosphere, which act as catalysts for ozone destruction.

Stratospheric ozone concentrations and trends vary greatly between the tropics and regions nearer the poles. While ozone is likely to remain below historical levels in tropical regions for decades to come, ozone levels outside the tropics are expected to recover over coming decades as emissions of industrial ozone-depleting substances controlled under the Montreal Protocol continue to decline.[51]

Greenhouse gases are expected to become the dominant driver of stratospheric ozone concentrations in the second half of the century, once concentrations of other ozone-depleting substances are low. Given their opposing effects, the impact of global greenhouse gas emissions on future ozone levels will depend on emissions of nitrous oxide relative to carbon dioxide and methane.

If strong climate policy action is taken to mitigate carbon dioxide and methane emissions but no action is taken to curb nitrous oxide emissions, ozone concentrations could fall to below historical levels by the end of the century, particularly in the tropics. Conversely, if strong action is taken to mitigate nitrous oxide but carbon dioxide and methane concentrations continue to rise steeply, too much stratospheric ozone could become a problem outside the tropics by the end of the century.[52]

Ocean acidification

The absorption of carbon dioxide by the ocean surface makes it more acidic.[53] There are signs that this surface layer acidification is beginning to have negative impacts on some marine ecosystems.

[50] Ravishankara et al., 2009. Nitrous oxide is not covered by the Montreal Protocol.

[51] World Meteorological Organization (WMO), 2018, p.3.

[52] Butler et al., 2016.

[53] "When carbon dioxide mixes with the water it is partially converted into carbonic acid, hydrogen ions (H^+), bicarbonate (HCO_3^-), and carbonate ions (CO_3^{2-}). Seawater can assimilate much more CO_2 than fresh water. The reason for this is that bicarbonate and carbonate ions have been perpetually discharged into the sea over aeons. The carbonate reacts with CO_2 to form bicarbonate, which leads to a further uptake of CO_2 and a decline of the CO_3^{2-} concentration in the ocean. All of the CO_2- derived chemical species in the water together, i.e. carbon dioxide, carbonic acid, bicarbonate and carbonate ions, are referred to as dissolved inorganic carbon (DIC). This carbonic acid-carbonate equilibrium determines the amount of free protons in the seawater and thus the pH value." (World Ocean Review).

For example, ocean acidification off the west coast of the United States has affected the ability of shellfish such as oysters to form shells, so they need to work harder to build them.[54] Recent research also indicates that ocean acidification could enable toxic blue-green algae to become dominant in some marine ecosystems, posing further threats to coastal communities, aquaculture and fisheries.[55]

Effects on water, air and soil

Human interventions in the nitrogen cycle have underpinned unprecedented levels of agricultural production. However, they have also led to large quantities of reactive nitrogen being released into terrestrial and aquatic ecosystems. Once released into ecosystems, reactive nitrogen is constantly moving between air, water and soils, and converting between nitrate, ammonium, nitrous oxide and other reactive forms. This makes it very difficult to track and contain it.[56]

Reactive nitrogen leaching into waterbodies can, together with other nutrients, cause excessive growth of plants and algae, leading to changes in ecosystem functioning and health. At very high levels of plants and algae, respiration rates can be high enough to remove all the oxygen from the water and create dead zones where fish and other aquatic species are unable to survive. Over 880 ocean dead zones have already been identified around the world, and this number is rising.[57] High levels of nitrates in drinking water are also linked to adverse human health outcomes.[58]

Reactive nitrogen is also linked to the formation of particulate matter, one of the main ingredients of air pollution and urban smog. The concentrations of airborne particulate matter continue to exceed World Health Organization standards in many major cities around the world.

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[54] University of Washington.

[55] Riebesell et al., 2018.

[56] Galloway et al., 2003.

[57] OECD, 2018b, p.4.

[58] Recent reviews have investigated the links between high nitrate levels in drinking water and human health. Ward et al. (2018) found increased risks of methemoglobinemia (blue baby syndrome), colorectal cancer, thyroid disease and neural tube defects from high nitrate ingestion. Similarly, a recent study in Denmark found significantly increased risks of colorectal cancer in drinking water levels above 3.9 milligrams nitrate per litre (Schullehner et al., 2018).

Source: russellstreet

Figure 2.6. As well as being a powerful greenhouse gas when it is in the form of nitrous oxide, nitrogen can contribute to smog and local air pollution when it is emitted from petrol and diesel engines as nitrogen dioxide.

In soils, reactive nitrogen can make the soil more acidic and may damage the microbial communities that maintain its fertility. The impacts of reactive nitrogen on soil microbes are not well understood and this remains an active area of scientific research.

Conclusion

Significant differences are apparent between all three main anthropogenic greenhouse gases, both in terms of the way they are produced and removed from the atmosphere and the warming they cause while they are there. In addition, the emission of each gas results in a range of differing additional environmental impacts.

These differences suggest that from a scientific perspective it may be appropriate to treat the various impacts of each gas as separate environmental problems. Doing so does not preclude combining the impact of the gases where that impact is similar. For example, it is still possible to calculate and discuss the current warming impact of all three gases combined.

However, in order to consider their ongoing impact and practical policy responses, it is necessary to consider how they come to be produced or co-produced (including their historical trajectories), and how their impacts relate to one another.

With this in mind, the next chapter examines the key sources and sinks of past and present biological emissions in New Zealand that have been driven by the major land transformations that have occurred. It is against this backdrop that future efforts to reduce biological emissions need to be evaluated, with careful consideration of the impacts they might have on our landscapes.

3 New Zealand's biological sources and sinks

Key points

- Humans have transformed Aotearoa New Zealand's landscapes since their arrival. Both the clearing of the land and its subsequent use for agricultural production have made large contributions to warming.
- Carbon dioxide emissions from deforestation are by far the largest contribution New Zealand has made to planetary warming to date.
- The next largest contributions to warming have come from biological methane emissions from New Zealand's livestock and carbon dioxide emissions from burning fossil fuels. Nitrous oxide emissions from livestock and fertiliser use have caused the least warming to date.
- The land still holds vast pools of carbon in the soil and plants that remain, but climate change itself will increase the risk of this carbon being released into the atmosphere.

The expansion and growth of human populations the world over has shifted huge quantities of carbon, as methane and carbon dioxide, and nitrogen, as nitrous oxide, into the atmosphere. Successive waves of people arriving and transforming New Zealand's landscapes have contributed to that.

Chapter three examines the past and present sources and sinks of biological emissions in our landscapes. It discusses the potential for carbon pools to be increased either by expanding the total land area in forestry and other high carbon storage land uses, or increasing the storage capacity under existing land uses by modifying management practices.

Land use change and its impact on terrestrial carbon pools

Deforestation has occurred on a vast scale in Aotearoa New Zealand, releasing a huge volume of carbon dioxide into the atmosphere. But the cleared land did not remain barren. Much of it was put into productive use, while some was left to regenerate back into native forest. The crops, pasture and plantation forests that replaced many native forests all hold carbon. The soils also still hold vast amounts of carbon (see figures 3.1 and 3.2).[1]

So while 3.4 gigatonnes of carbon was released by clearing the forests, 0.1 gigatonnes of carbon has been sequestered through soil improvement under pasture. New Zealand's net emissions from land use change since human arrival is estimated at 3.3 gigatonnes of carbon.[2]

Three gigatonnes of carbon is roughly equivalent to 12 gigatonnes of carbon dioxide,[3] and represents a huge transfer from the biosphere to the atmosphere. But even more remains – the equivalent of 17 gigatonnes of carbon dioxide or 4.5 gigatonnes of carbon remain stored in New Zealand's landscapes.

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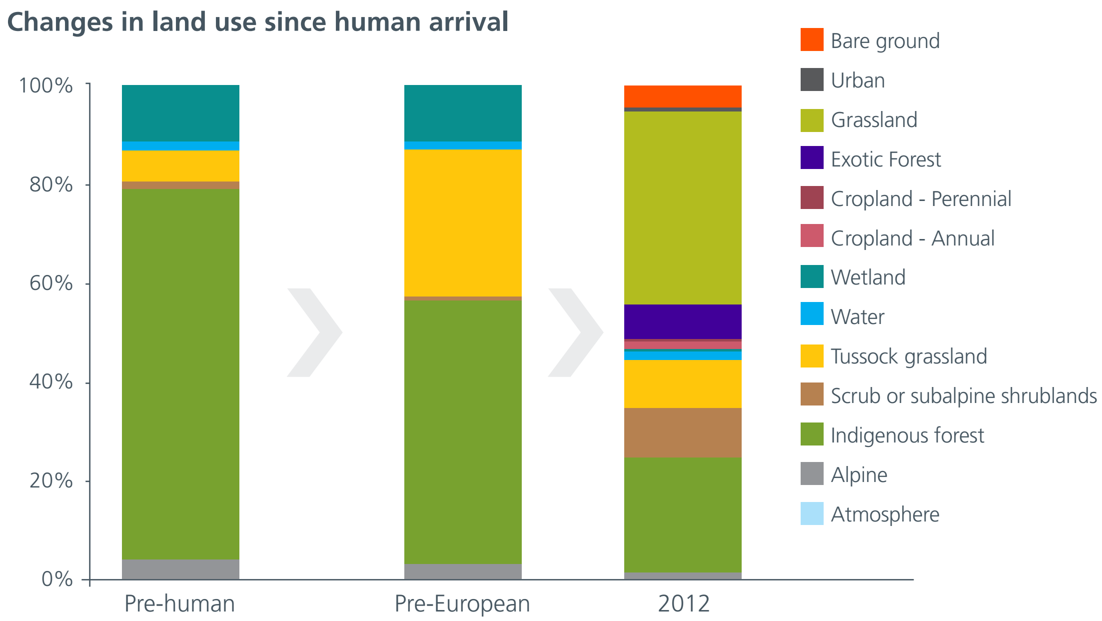
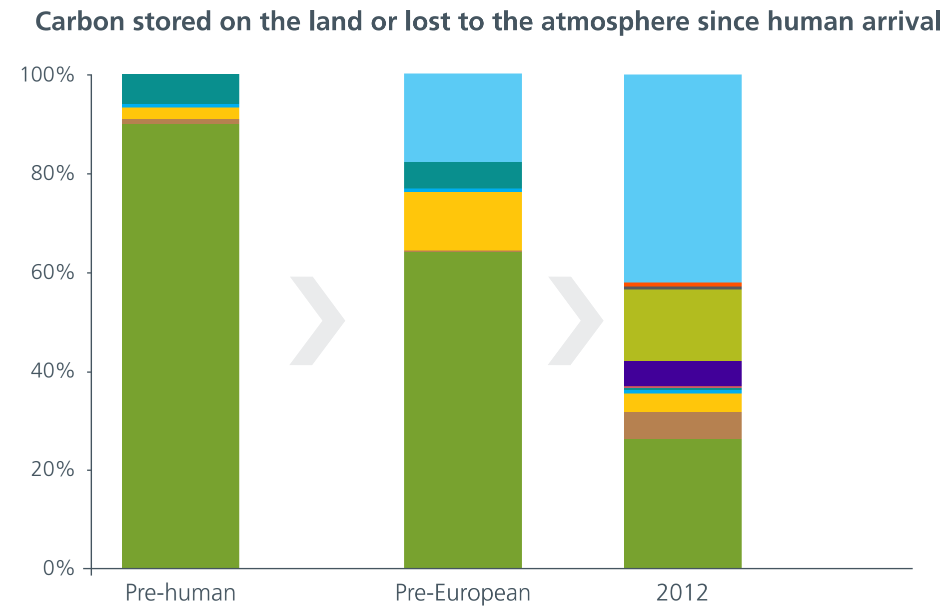
[1] In the New Zealand Greenhouse Gas Inventory, productive pasture soils hold slightly more carbon than those under indigenous forest.

[2] Due to limited information, these estimates are approximate, intended to give a sense of scale of the emissions of carbon dioxide from historical changes. New Zealand's historical land use emissions were calculated by the office of the Parliamentary Commissioner for the Environment using historical land cover data and estimates of carbon in land cover types.

Historical land areas were estimated from spatial data obtained from Manaaki Whenua – Landcare Research. Historical land cover estimates are based on LCDB 3, with wetlands and tussock extent (Ausseil et al., 2011; Weeks et al., 2012). Land use in 2012 is estimated from the latest New Zealand Land Cover Database 2012 – version 4.1 MfE. The carbon estimates for soils and vegetation are from the New Zealand Greenhouse Gas Inventory (Ministry for the Environment, 2018a; Ausseil et al., 2013, 2015; and Holdaway et al., 2017). These calculations do not include estimates of changes in methane and nitrous emissions from land conversion.

[3] The terms carbon and carbon dioxide are sometimes used interchangeably when discussing climate change, but this can lead to confusion because a molecule of carbon dioxide is 3.7 times heavier than an atom of carbon. In this chapter, values are tonnes of carbon unless stated otherwise.

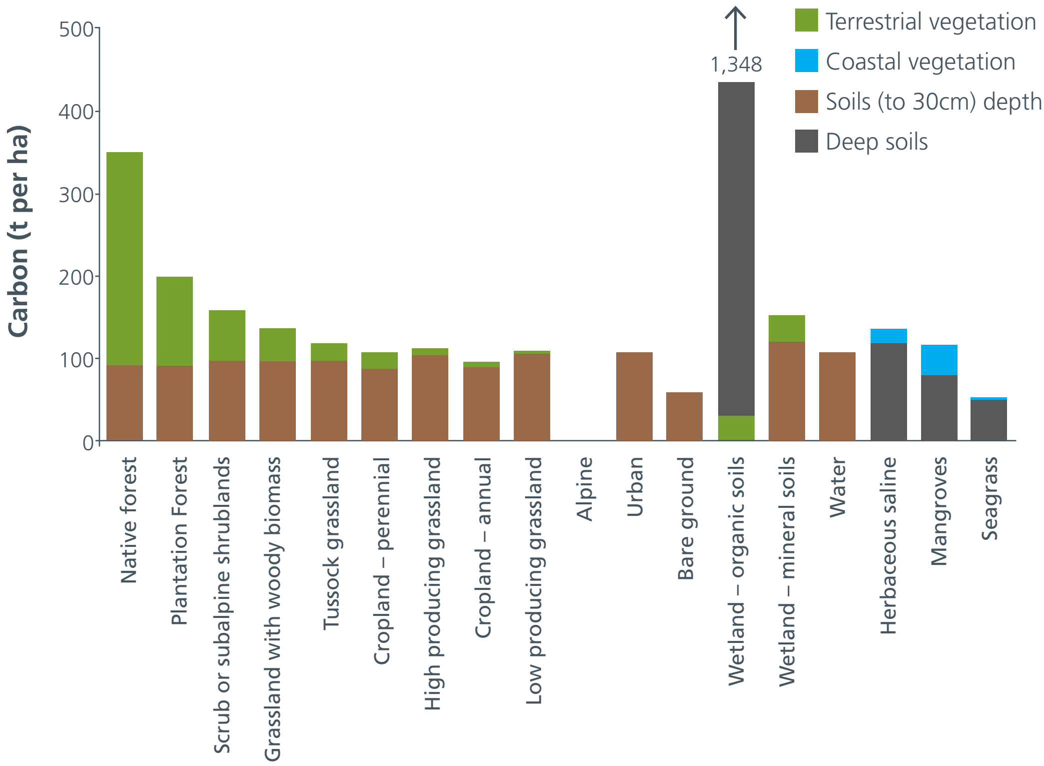




Source: Parliamentary Commissioner for the Environment

Figure 3.1. The composition of the ecosystems on New Zealand's landmass has changed significantly since humans arrived, and with it the amount of carbon stored within the plants and soil.[4]

[4] Carbon in pre-European and 2012 landscapes is presented as a percentage of the total carbon estimated in pre-human landscapes. Note that while large amounts of carbon have been released into the atmosphere, more than half remains stored in our land.



Source: Ausseil et al., 2013; 2015; Bulmer and Townsend, 2018; Holdaway et al., 2017; MfE, 2018a.

Figure 3.2. Carbon currently stored in different ecosystems in New Zealand on a per hectare basis.[5]

Forests

New Zealand's native forests cover approximately 7.8 million hectares and hold an estimated 1.8 gigatonnes of carbon in biomass.[6] The majority of this carbon, 1.7 gigatonnes, is stored in old-growth forests and is considered to be carbon neutral. That is, the forest is accumulating carbon in new growth at a rate approximately equal to the carbon being lost to the atmosphere through the respiration of microbial and fungal communities feeding on decaying organic matter.

A smaller fraction of the native forest estate, 1.3 million hectares, is considered to be regenerating or 'mid-successional' forest. It includes areas that have been cleared in the past from natural disturbances (e.g. fire or landslides) or human disturbances, and left to revert to forest. These forests are often composed of serial or scrub vegetation, such as mānuka or kānuka, or the exotic shrubs, gorse and broom, that provide a nursery habitat and will eventually be outgrown by broadleaved species and podocarps.

[5] Deep soils are to 1 m in the marine ecosystems (Bulmer and Townsend, 2018), and on average to 3.9 m for organic wetlands (Ausseil et al., 2015). Note that a limited number of samples and sites were measured in these studies, and estimates must therefore be treated with caution.

[6] Holdaway et al., 2017. Estimate a total biomass stock of 3.6 Gt across the pre-1990 natural forests. The carbon content of plant tissue is approximated at 50% of plant biomass (after Holdaway et al., 2014a).

An estimated further 0.1 gigatonnes of carbon is currently stored in these regenerating native forests. These forests are currently acting as a sink, sequestering carbon at an estimated rate of 1.4 tonnes of carbon per hectare per year.[7]

As New Zealand's pasture grasslands expanded, the easy availability of native timber dwindled. To meet future timber demands, New Zealand began planting trees from around the world, and implementing breeding programmes to improve growth rates and wood quality.

Today, exotic forest plantations cover an estimated 1.7 million hectares of land and hold an estimated 0.1 gigatonnes of carbon. The overwhelming majority (around 90 per cent of the total plantation forest estate) is genetically improved radiata pine plantations, but they also include Douglas fir, cypress and eucalyptus species and small areas of other exotic hardwood and softwood species.[8]

Carbon storage patterns in plantation forests differ from those in native forests. Once the forest is planted, it accumulates and stores carbon as it grows. But at the end of the cycle the wood is harvested, and the carbon stored in those trees is removed. In reality, the carbon is not lost to the atmosphere instantly; wood is taken offsite and committed to its next purpose. Some of it will be locked up for very long periods in everyday items like furniture.

Since radiata pine is a general purpose species with variable wood qualities, much is transformed into material like pulp and paper and ultimately decays much more quickly (see box 3.1 on harvested wood products (HWPs)). What is left behind following harvest – the slash above ground (leaves, branches) and biomass below ground (roots) – is left to decompose onsite, returning nutrients to the soils and much of the carbon to the atmosphere.

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[7] Holdaway et al., 2017.

[8] Ministry for Primary Industries, 2017a, p.9.

Source: James Anderson, World Resources Institute

Figure 3.3. Logs awaiting export at Wellington Port. Depending on its use, the carbon in harvested plantation timber may be rapidly released back into the atmosphere (if used for heating or paper), or may stay locked up for many years (if used as a building material). Such variety makes it difficult to calculate how much, carbon is stored in plantation forests, and for how long.

This describes the on-ground reality of planting and harvesting one rotation, but most plantation forests are quickly replanted. So to estimate the total carbon stored in plantation forests, the age, structure and area of all forests need to be considered. This includes the rate of afforestation and deforestation as well as harvest age.

Without significant new planting, New Zealand's plantation forests are about to become net sources of carbon emissions to the atmosphere. This is the legacy of the net expansion of plantation forests in the 1990s with trees now reaching harvest age. As forest expansion has now halted, there is a shortfall of younger trees to act as a buffer to offset these looming harvests. This so called 'wall of wood' will lead to a large net loss of carbon from the plantation forest estate in the short term. The loss will only be compensated if new trees are replanted and grown to replace those being cut down.[9]

[9] Note that this is describing the actual changes in carbon stored in the plantation forests over time. However, how this is accounted for may differ. Accounting rules are discussed later in the report.

Carbon in soils

The amount of carbon stored in the biomass of plants can vary considerably (see figure 3.2). Mature native forests contain over thirty times more carbon in the trees and plants than that held by the herbs and grasses of high production grasslands.

Carbon is not just stored in plant tissue, it is also held in the soil. Carbon stored in soil makes up over half of New Zealand's terrestrial carbon pool today. Compared with soil carbon stocks globally, the amount of carbon stored in soils across New Zealand is high. However, soil gains or losses of about 10 tonnes of carbon per hectare (around 10 per cent of its total) can occur with changes in land use.

A major challenge for measuring soil carbon stocks is the large variation in the amount of soil carbon even within a single paddock or farm.[10] The amount of carbon in soils depends on several factors, including the vegetation of past and present land uses, soil type, composition of the mineral bedrock, climate and topography and management. Detecting changes in soil carbon stocks is problematic because of the high variability and very slow rates of change, but new, lower cost methods to detect changes are emerging.

Based on the latest New Zealand Greenhouse Gas Inventory calculations, productive grassland soils on average contain more carbon than forest soils. In converting grasslands back to scrub, native forests or exotic plantations, small soil carbon losses can be expected. But there is much more carbon in the biomass of trees than grasses, so, ultimately, much more carbon is sequestered in a forest ecosystem than a grassland.

Wetlands

An estimated 2.3 million hectares (around 90 per cent of the original extent) of wetlands have been drained and cleared in New Zealand. Two thirds of this has been for conversion to pasture grasslands while the rest is under plantation forests, cropland and urban development.[11] Wetlands can be on organic or mineral soils – the vast majority, both historically and today, are on mineral soils.

Freshwater wetlands on mineral soil capture carbon both through the accumulation of dead organic matter and accumulation of carbon in soils and sediments in runoff. Once settled in wetland soils, decomposition of dead organic matter is slower than in non-saturated soils as the low oxygen environment limits the respiration rates of the decomposing organisms.[12] Seasonally dry wetlands, or ephemeral wetlands, store less carbon than 'permanent' wetlands, demonstrating the importance of moisture in limiting the oxygen needed for soil microbes to decompose decaying material.

Organic soils are those comprised of 30 per cent or more organic matter (or 18 per cent or more carbon content).[13] Their formation occurs over hundreds to thousands of years as dead organic matter accumulates in wetlands and decomposition is restricted

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[10] Whitehead et al., 2018.

[11] Ausseil et al., 2015.

[12] The diffusion rate of oxygen through water is 5 to 10 thousand times (temperatures of 60 °C and 20 °C respectively) slower than it is in air. As a result, waterlogging often leads to low oxygen, or anaerobic conditions (Richard, 1996).

[13] Hewitt, 2010.

by the lack of oxygen. As a result, organic wetland soils, or peatlands, are estimated to hold an average of 102 tonnes of carbon per hectare in just the top 30 centimetres of soil. If the entire depth of the peatland is considered however, carbon density estimates increase to an average of 1,348 tonnes of carbon per hectare (to an average depth of 3.9 metres).[14]

Coastal ecosystem carbon storage

New Zealand's coastal ecosystems include seagrasses, tidal marshes and, in the north, mangroves. Similar to their terrestrial counterparts, coastal wetlands sequester carbon in their sediments through the accumulation of dead organic matter and sediment from soil runoff. Low rates of microbial decomposition keep the carbon locked up there.

In temperate southern waters, New Zealand's coastal ecosystems support a smaller carbon pool than would be observed around a similar length of coastline in a warmer, more tropical setting. Growing at the southernmost extent of the range for its genus, New Zealand's single mangrove species is stunted compared to its relatives in warmer climates. But, as described above, the vast majority of carbon held in these ecosystems is stored in sediments, bound by roots rather than the visible vegetation itself.

Despite existing mangrove wetlands containing large amounts of carbon per hectare, and having other environmental benefits, their mitigation potential appears limited in New Zealand, given the comparatively small area they occupy.

Biological emissions from agriculture

Due to the nature of New Zealand's economy, biological emissions account for a particularly high proportion of New Zealand's annual greenhouse gas emissions.

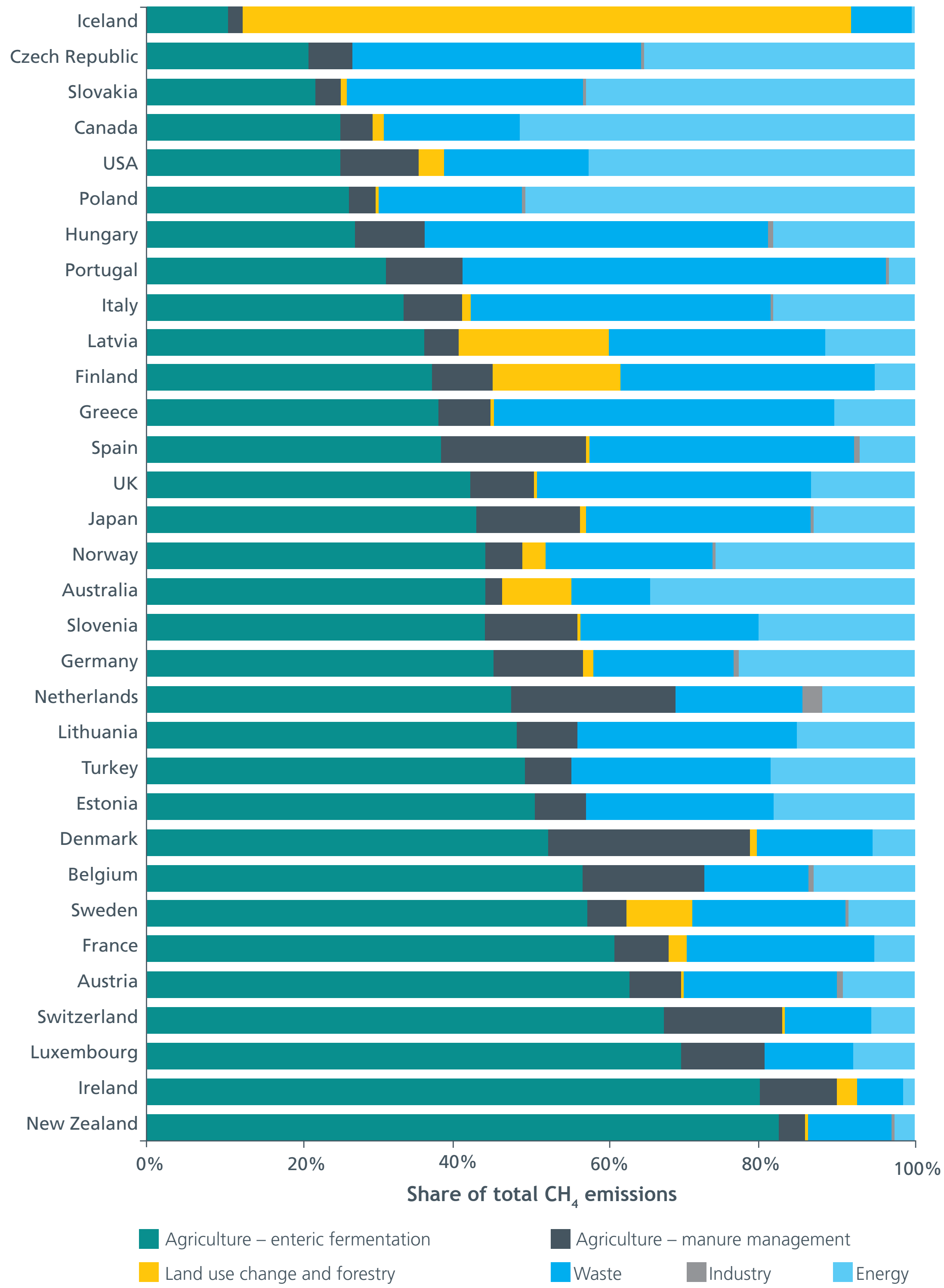
Methane emissions from agriculture

In many other countries, a large proportion of any methane emissions come from the extraction of oil and gas. In New Zealand this source accounts for a much smaller fraction. New Zealand is atypical in this regard – in most other OECD countries, energy and waste account for a larger share of total methane emissions (see figure 3.4).

New Zealand's per capita emissions of methane remain significantly higher than the OECD average. Total methane emissions have remained roughly constant over the last three decades, with emissions only about four per cent higher in 2016 than they were in 1990.

Biological methane from agriculture accounts for around 86 per cent of New Zealand's total methane emissions. A further 11 per cent comes from the waste sector (mainly from solid waste disposal) and around three per cent from the energy sector (mainly leaks and releases from oil and gas infrastructure).

[14] Ausseil et al., 2015, Table 4.



Source: UNFCCC

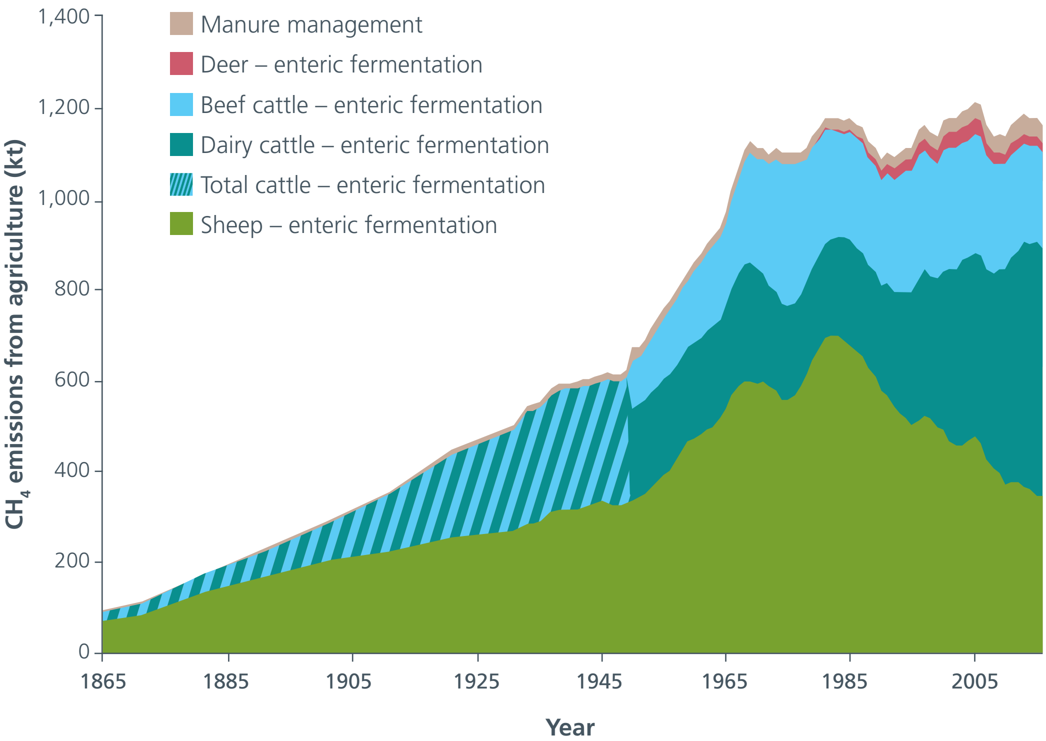
Figure 3.4. Sources of methane emissions in selected OECD countries, 2016.[15]

[15]Based on national greenhouse gas inventory submissions to the United Nations Framework Convention on Climate Change (UNFCCC, 2018).

In New Zealand, nearly all biological methane from agriculture comes from the digestive systems of ruminants produced via a process known as enteric fermentation. The source of methane from enteric fermentation has shifted over time with the changing composition of the national herd. In 2016, around half came from dairy cattle, one third from sheep and about one fifth from non-dairy cattle.[16]

The source of New Zealand's biological methane from agriculture also differs from many other developed countries. In other OECD countries, manure management often accounts for a larger share of methane emissions from the agriculture sector. This is because in many countries livestock farming is dominated by housing-based farming systems that collect effluent in ponds or slurry systems. This leads to significant amounts of methane being released from the waste as it decomposes under anaerobic conditions. The use of housing-based systems in New Zealand remains relatively uncommon.

Over all, New Zealand's historic methane emissions from agriculture have closely followed the changes in livestock populations as illustrated in figure 3.5.



Source: Data adapted from Ausseil et al., 2013, with updates primarily from StatsNZ 2016b and MfE, 2018a

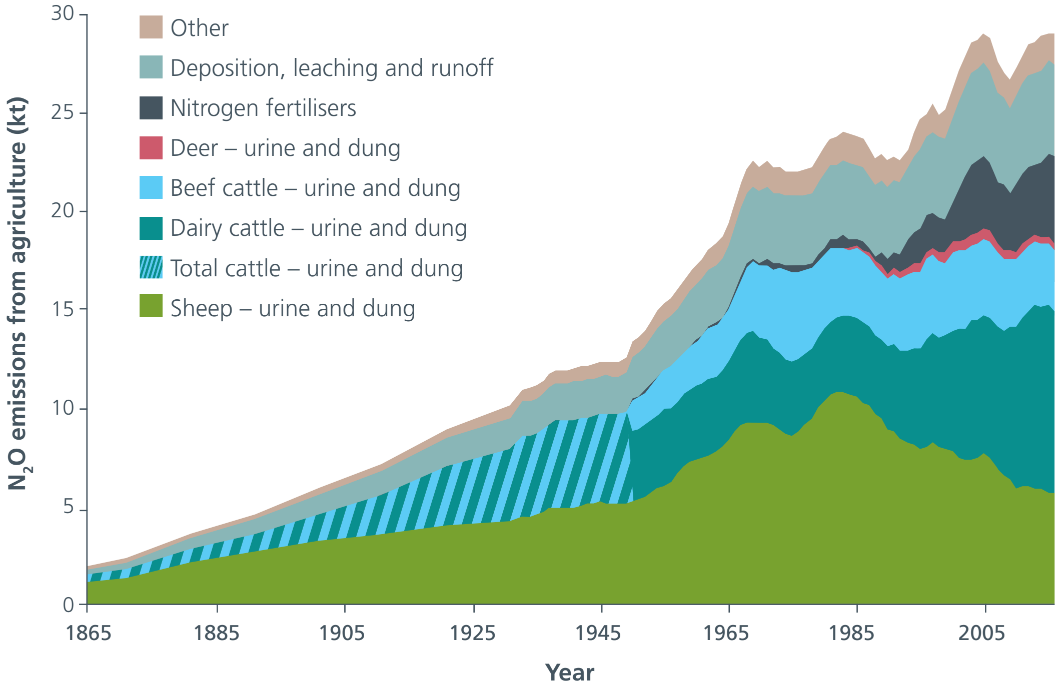
Figure 3.5. New Zealand's methane emissions from agriculture, 1865–2016.[17]

[16] Ministry for the Environment, 2018a.

[17] Excludes CH_4 emissions from field burning of agricultural residues. These accounted for 0.07% of New Zealand's agricultural methane emissions in 2016.

Nitrous oxide emissions from agriculture

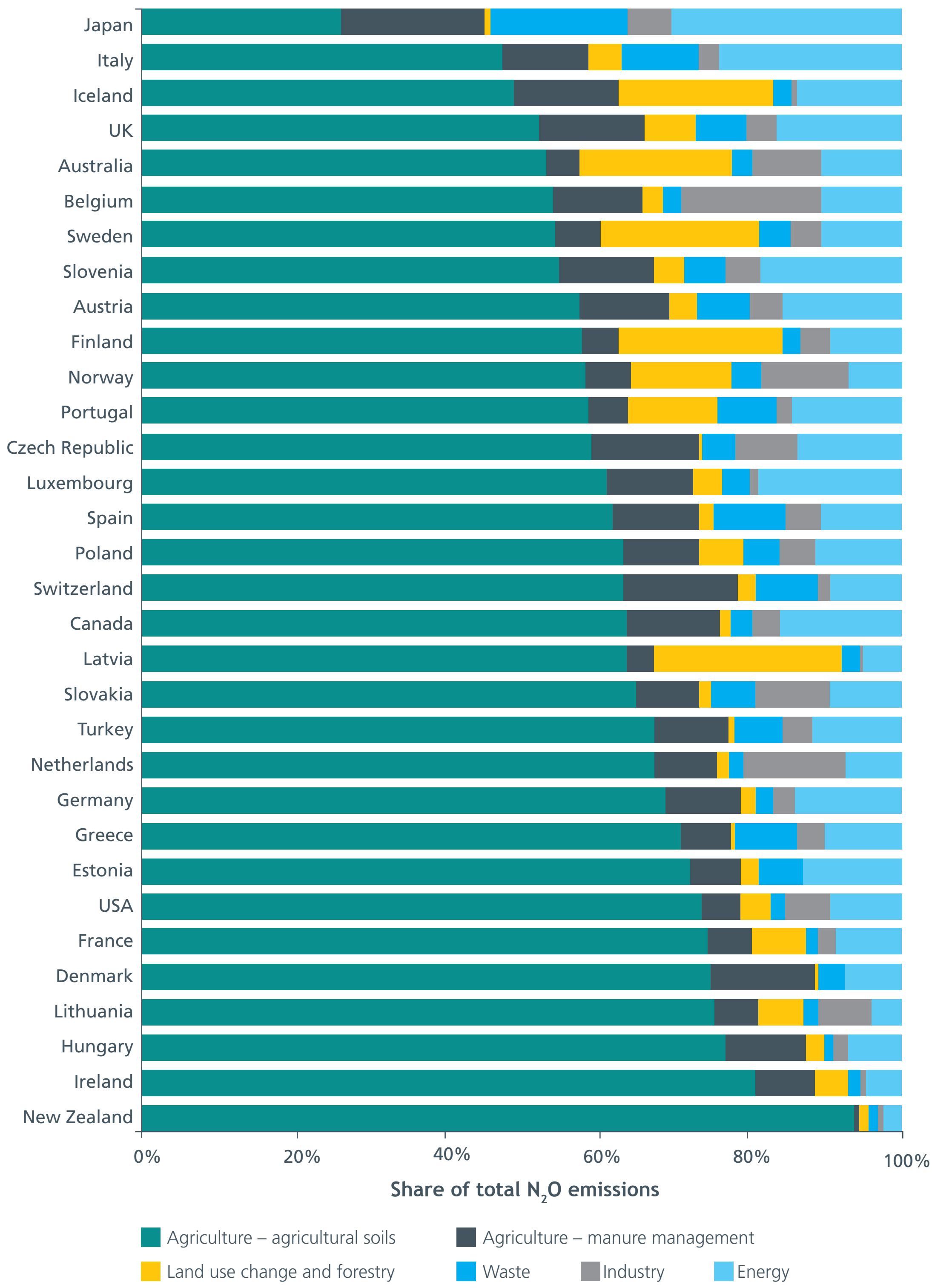
Unlike methane, nitrous oxide emissions have increased significantly over recent decades. Although not the main direct source, the main driver for the recent trend has been the use of nitrogen fertiliser, the use of which has increased six-fold since 1990 (see figure 3.6).



Source: Data adapted from Ausseil et al., 2013, with updates primarily from StatsNZ, 2016b and MfE, 2018a

Figure 3.6. New Zealand's nitrous oxide emissions from agriculture, 1865–2016.[18]

[18] 'Other' includes N_2O emissions from crop residues, manure management, cultivation of organic soils, and urine and dung of pigs and goats.



Source: UNFCCC

Figure 3.7. Source of nitrous oxide emissions in selected OECD countries, 2016.[19]

[19] Based on national greenhouse gas inventory submissions to the UNFCCC.

New Zealand's total nitrous oxide emissions increased by almost a third between 1990 and 2016, when they reached 30,600 tonnes.[20] More than 90 per cent of this came from agricultural soils, predominantly caused by urine and dung from grazing livestock.[21]

Prior to the 1990s, New Zealand's nitrous oxide emissions came almost entirely from sheep and cattle. Today, around 20 per cent comes directly from the use of nitrogen fertilisers. This reflects a shift in pasture management that has seen reliance on biological nitrogen fixation (mainly by the legume white clover) replaced with nitrogen fertiliser as the dominant input of reactive nitrogen for many of New Zealand's farming systems.

The use of nitrogen fertilisers became much more widespread following the opening of the Kapuni urea plant in Taranaki in 1982. This plant was part of the Think Big industrial development policy and was designed to use up some of the gas discovered at the Maui gas field.[22]

Nitrogen fertiliser use subsequently rose tenfold, from around 40 kilotonnes of nitrogen in 1985 to over 430 kilotonnes of nitrogen in 2016. Over the same period, the amount of nitrogen fixed by biological nitrogen fixation decreased from around 510 kilotonnes of nitrogen in 1985 to around 350 kilotonnes of nitrogen in 2016.[23] The increased availability of cheap nitrogen fertiliser was one of the drivers behind the intensification of New Zealand's farming systems that has occurred since the 1980s.[24] The proportion of nitrous oxide emissions from agriculture in New Zealand is currently the highest of all OECD countries (see figure 3.7).

When livestock are farmed in an intensive way, nitrogen fertiliser is applied to the land to maximise pasture growth. But if the amount of nitrogen applied exceeds what plants can take up, excess nitrogen may be lost immediately and end up in water or the atmosphere.[25]

Plants can accumulate high levels of nitrogen, and consequently, animals can consume much more nitrogen than they need. Surplus nitrogen is mostly expelled in urine. As dairy cattle have much bigger bladders than sheep, they contribute much more nitrogen-rich urine to the land in concentrated 'patches'.

The surplus nitrogen can result in nitrous oxide being released to the atmosphere and nitrate leaching into waterways. In most OECD countries, the amount of surplus nitrogen (known as the nitrogen balance) has decreased since 1990, but in New Zealand it has risen significantly (figure 3.8).

[20] Equivalent to 9,126 ktCO_2-e using the AR4 GWP_{100} value of 298 for nitrous oxide.

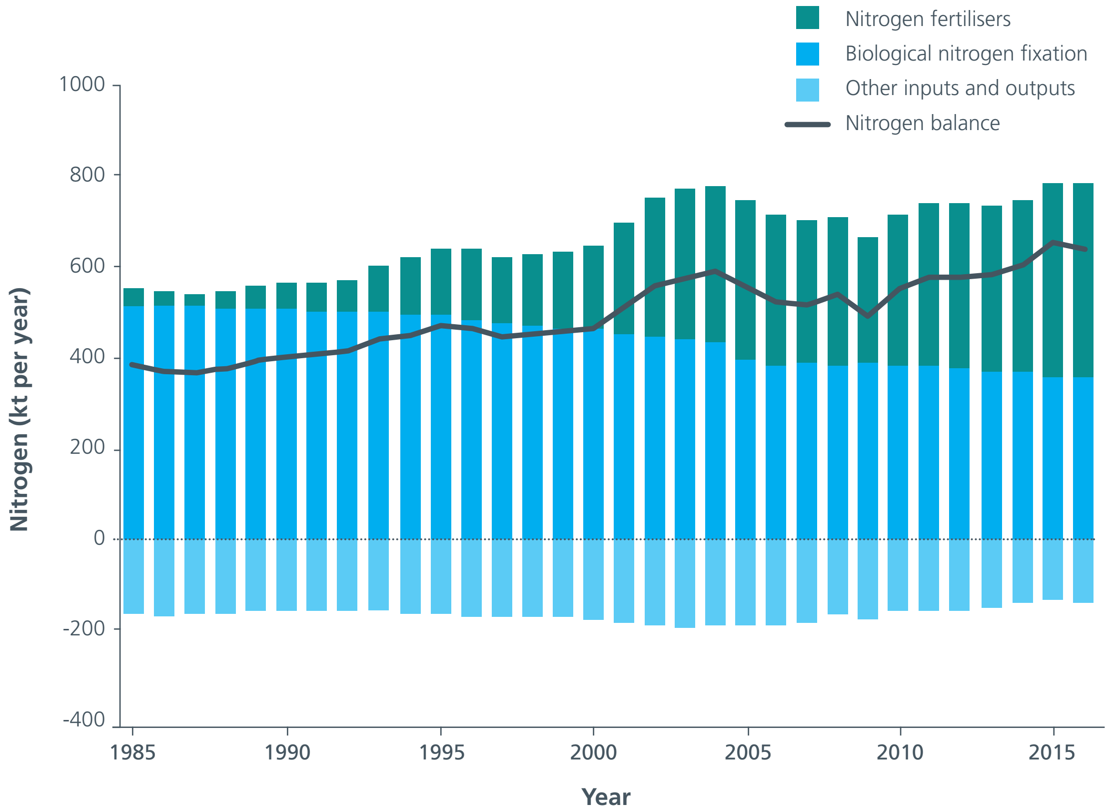
[21] The remainder comes from land use change and forestry, wastewater treatment, and fossil fuel combustion and industrial processes.

[22] Roberts, 2008.

[23] OECD, 2018b.

[24] Two other drivers were the increased use of supplementary feed such as palm kernel extract (PKE) and the development of irrigation schemes.

[25] Especially during irrigation or high rainfall events.



Source: OECD Agriculture Statistics database

Figure 3.8. New Zealand's nitrogen balance, 1985–2016.[26]

When urine, dung or nitrogen fertiliser is put on fields, some of the nitrogen volatilises back into the atmosphere as ammonia gas and is subsequently deposited elsewhere by rainfall. Some of the nitrogen may also leach into waterways. The indirect nitrous oxide emissions from these processes can be significant – in 2016 they were estimated to account for 16 per cent of nitrous oxide emissions from agricultural soils.

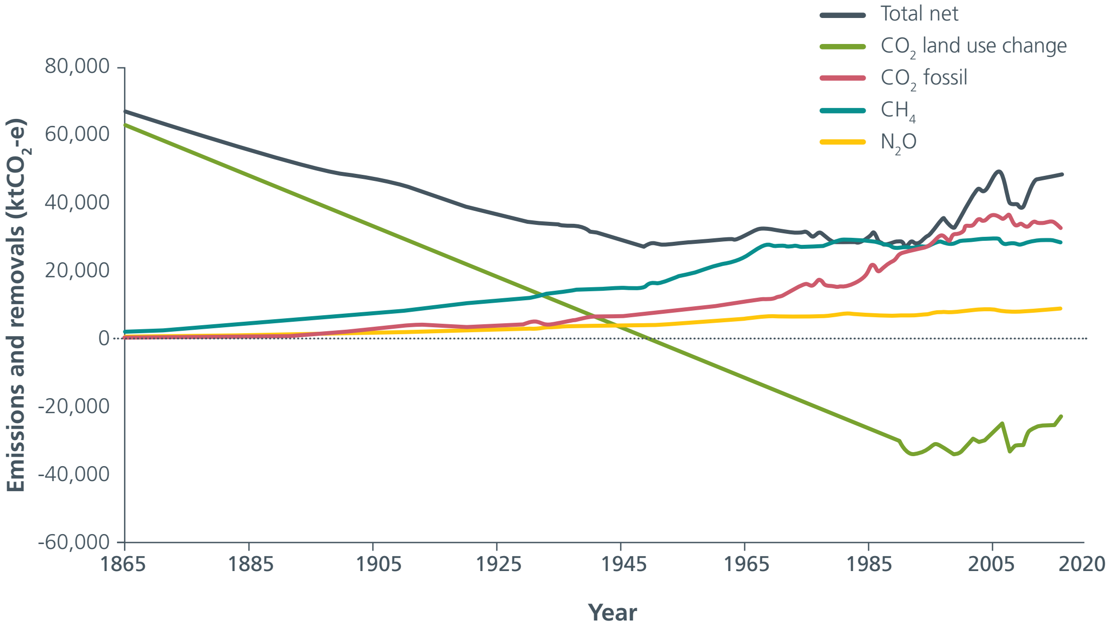
Contribution of New Zealand's greenhouse gases to warming

Figure 3.9 shows the contribution to warming from selected human activities in New Zealand, given the historical trends in livestock numbers and terrestrial carbon storage outlined above.

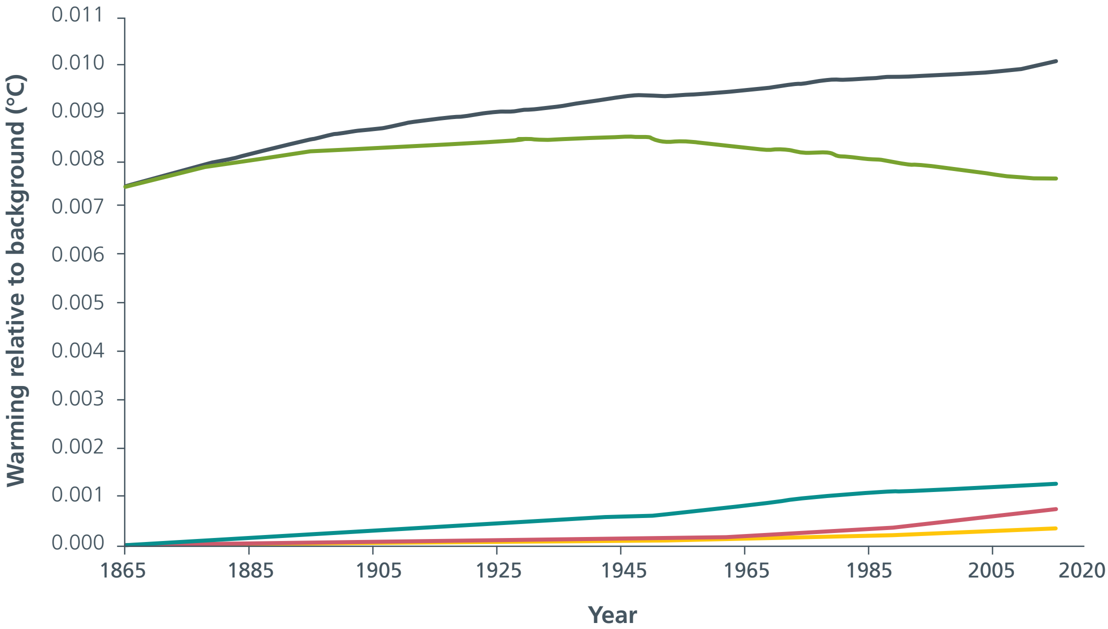
New Zealand's three main anthropogenic greenhouse gases have had very different impacts on the climate system to date.

[26]Based on statistics from the OECD Agriculture Statistics database (2018a). Note that the nitrogen balance is the difference between the nitrogen inputs entering a farming system and the nitrogen outputs leaving the system. A positive nitrogen balance indicates a surplus of reactive nitrogen and the risk of pollution to soil, water and air.

Annual emissions and removals



Cumulative temperature response



Source: Calculated in-house and Andy Reisinger pers. comm.

Figure 3.9. Contribution to warming from selected human activities in New Zealand up to 2016.[27]

[27] Carbon dioxide equivalent calculated using the global warming potential 100 metric described in detail in chapter four.

Carbon dioxide

Fossil emissions of coal, gas and oil increased gradually for about a century, then increased much more quickly over the next half century, peaking at almost 40,000 kilotonnes of carbon dioxide in the 2000s (see figure 3.9). Annual fossil carbon emissions have since roughly stabilised but remained high.

The warming impact of these emissions increased year on year as fossil carbon dioxide, being long-lived and part of the slow geological carbon cycle, accumulated in the atmosphere. Additional warming from this source can be expected for as long as fossil emissions continue.

With limited historic information on timing it is only possible to crudely estimate the annual net emissions associated with deforestation and the large changes in land use described previously. But the approximate scale of warming associated with land use changes is readily apparent, dwarfing by roughly seven times the contribution from fossil emissions.[28] The halting of native deforestation, coupled with extensive planting of plantation forests, has increased carbon storage in recent decades. As figure 3.9 indicates, this has lowered the cumulative warming impact. However, a large of amount of warming remains.

Methane

The warming contribution caused by methane emissions from livestock in New Zealand is considerable – cumulatively it remains over twice that of all warming from fossil fuels to date. But methane emissions have begun to level off and even drop a little since the 1990s and this has had an impact on warming from this source.

As part of the research for this report, some modelling work was commissioned to better understand the relationship between methane emissions from New Zealand's livestock and the global temperature response. The results, which have been published previously, showed that holding New Zealand's methane emissions from livestock steady at 2016 levels would cause additional warming of 10–20 per cent above current levels by 2050. This warming would increase to 25–40 per cent by 2100.[29]

If New Zealand wished to stabilise the contribution of its livestock methane to warming at its 2016 level, it would need to reduce livestock methane emissions by around 10–22 per cent by 2050. If New Zealand wished to stabilise its contribution to warming at a lower level, greater emissions reductions would be needed.

Nitrous oxide

The cumulative warming impact of New Zealand's nitrous oxide emissions to date is much less than that of methane from livestock or fossil carbon. But nitrous oxide emissions have been steadily rising.

[28] This contrasts markedly with the global pattern where only about a third of the emissions of CO_2 since 1750 were due to land use change (Ciais et al., 2013, p.467).

[29] Parliamentary Commissioner for the Environment, 2018.

Since nitrous oxide has a longer lifetime than methane, there will be a much longer lag time between nitrous oxide emissions levelling off and a global temperature response.

Increasing the carbon storage capacity of our land

New Zealand's landscapes today are a mosaic of different land uses, many of which are still in a state of flux. As land use changes so too does the quantum and location of carbon storage.

New Zealand's historic transfer of carbon from land-based pools to the atmosphere suggests that our landscapes have the potential to hold considerably more carbon than they do today.

Carbon pools can be increased by either expanding the total land area in high carbon storage land uses, or increasing the storage capacity under existing land uses by modifying management practices.

Increasing carbon in forests

Establishing new plantation and native forests on land currently under pasture or scrub could sequester millions more tonnes of carbon. Radiata pine trees and other quick-growing species can do this rapidly; native species, typically considered to be slower growing,[30] could ultimately store a large amount of carbon too.

Under current silvicultural practices that aim to maximise the returns to land from timber, most plantation forests are grown on rotations of 25 to 30 years. The amount of carbon stored on this type of land will fluctuate as trees are established, mature and then harvested, with new seedlings being planted among the decaying remains of the previous rotation.

If maximising carbon capture is the goal, simply extending the cycle by a few more years would increase the average carbon reservoir across the entire plantation forest estate. Plantations of radiata pine could feasibly be farmed for increasing carbon storage out to 60 years, or longer.[31] Modifying harvesting practices to keep a continuous cover could increase the size of the pool again. Leaving plantation forests in the ground to allow them to reach maturity, without extracting wood, could maximise the carbon storage capacity of the land.

The actual use of any timber harvested from a plantation forest will also make a difference to overall carbon storage. For example, harvesting trees and using the wood for buildings would have different carbon dioxide emission consequences than using them as a feedstock for biofuels (see box 3.1).

[30] It may be possible to make native trees grow faster. For example, Tāne's Tree Trust, a non-profit charitable trust focused on encouraging the use of indigenous New Zealand tree species, are hoping that under active forest management species such as tōtara may be able to grow at similar rates to some commonly planted exotic species.

[31] Woollons and Manly, 2012.

Box 3.1. What happens to the carbon in a tree when it dies?

The carbon stored in a tree does not instantly return to the atmosphere the moment a tree dies. This only happens as the plant material breaks down. Typically this occurs through a natural process of decay, although it can happen very rapidly if a tree burns.

Depending on the species and climate, some dead trees can hold their carbon for decades or even centuries – particularly if they remain standing. Fallen trees decay faster, but again, depending on the species and ground conditions, can also remain for some time.

Plantation forests are different in this regard. Exactly when any carbon returns to the atmosphere after a tree is harvested depends on the fate of the extracted timber. For example, the carbon from a tree turned into a tanalised post or incorporated into a building may remain out of the atmosphere for many decades. But if the same tree is turned into paper, the carbon may return to the atmosphere in a matter of months. Nevertheless, these harvested wood products (HWPs) are essentially temporary stores of carbon.

Any shift in the use of harvested timber towards more durable, long-lasting products will extend the life of this temporary store.[32] The converse is also true.

Any material substitution of emissions-intensive building materials with timber products could help extend the HWPs' carbon pool and its duration.[33]

Increased use of wood as a biofuel, while decreasing fossil fuel use, will nonetheless return carbon to the atmosphere much more quickly unless the carbon emitted is captured and stored.

Changes in domestic timber use will be important, but New Zealand exports most of its harvested timber, which is almost exclusively radiata pine. Most logs are exported to China, India and South Korea where they are converted into products with varying lifetimes.[34] When aggregated, the decay curves for these logs indicate that in just over two years half the carbon in exported logs has been returned to the atmosphere.

[32] Increasing the area of land in production forests will also have the effect of extending the size of the store too.

[33] Leskinen et al., 2018.

[34] Manley and Evison, 2017

Increasing soil carbon storage

Making incremental changes to the management of an existing land use has significant potential to increase carbon storage capacity if applied across the country. The largest land use in New Zealand is pasture. These grasslands occupy 39 per cent of the land area, or 10.5 million hectares.[35]

By world standards, New Zealand's pastoral soils hold a lot of carbon, and they have the potential to hold more. Management techniques aimed at increasing soil carbon are being explored. For example, experimental manipulations on study farms suggest that deep inversion tillage may increase the potential carbon storage capacity by shifting carbon rich soils down the soil profile where the decomposition rate could be slowed. Biochar, a stable form of carbon, can also be added to the soil. But such practices have not yet been proven to increase carbon in the long run or be economically feasible at present.

Removing or reducing the frequency of carbon losses associated with current management practices could increase the total carbon pool. Reducing tillage rates, using tillage hardware that minimises soil disturbance, and re-sowing as soon as possible after fields are ploughed may also limit carbon losses.[36]

An estimated 146,000 hectares of organic or peat soils are currently under pasture. Drainage of these soils has increased oxygen diffusion through air spaces in the soil profile, which promotes soil carbon losses through decomposition and respiration of the stored carbon back to the atmosphere.

Even now, 100 to 150 years since the drainage of these wetlands began, an estimated 0.5 to 2 megatonnes of carbon dioxide is released annually across New Zealand as a result of the continued decomposition of these carbon pools.[37] Re-flooding some of these landscapes and restoring the wetlands could halt these losses and, in the long term, potentially return far more carbon to the soils than forests could ever hold. But carbon accumulation in peat soils is very slow and as a consequence, so is the restoration of microbial communities and ecological processes that make these wetlands such effective sinks.[38]

[35] 10.5 million hectares were classed as 'High Producing Exotic Grassland' and 'Low Producing Grassland' in 2012 (Landcare Research New Zealand, LCDB v4.1).

[36] Whitehead et al., 2018.

[37] Prior to European settlement in New Zealand, an estimated 280,400 ha was in organic, or peat wetlands (Ausseil et al., 2015).

[38] Clarkson et al., 2017.

Source: pxhere.com

Figure 3.10. The type of soil and the way it is managed have a major impact on how much carbon is stored. In general, the less ploughing and disturbance the soil is subject to, the more carbon it will store, although unpredictable weather events, such as drought and heavy rain, can result in large and rapid losses of soil carbon.

In some cases, simply allowing ecosystems to react to land use changes could increase their carbon storage capacity. Over the last few decades, the increase in sediment loads from intensive land development coupled with tidal flow alteration from infrastructure have increased sedimentation rates in harbours. This has enlarged the habitat available for mangroves to establish. Allowing the natural establishment and expansion of mangroves across expanding intertidal mudflats has the potential to capture considerably more carbon, but this is strongly opposed by some parties.[39]

An increase of just one tonne of carbon per hectare, or about one per cent, averaged across the approximately ten million hectares currently in managed pasture could sequester ten megatonnes of carbon, or 36.7 megatonnes of carbon dioxide. By way of comparison, New Zealand emitted 33.4 megatonnes of carbon dioxide from fossil fuels in 2016. Although this appears promising and would be of some benefit, to offset just ongoing fossil carbon dioxide emissions would require additional storage of carbon in soils at this rate, annually, and for as long as the emissions continue.

Overshadowing all of these choices is the issue of unintended carbon loss. There is evidence to suggest that high intensity, irrigated pastures are incrementally losing, rather than gaining carbon.[40] The above scenario illustrates equally the magnitude of the risk associated with small losses multiplied over a large area.

[39]Lundquist et al., 2017.

[40]In a review of the effects of farming management practices on New Zealand's soil carbon, Whitehead et al. (2018) found that the impacts of irrigation where highly case study and climate specific, but when examined together suggest that intensively irrigated pastures may be losing carbon.

The amount of carbon in soil is highly variable and, while soil carbon can be gradually increased through careful management, it can also be rapidly lost by inadvertent actions. Increasing soil carbon stocks in New Zealand's grasslands under current intensive management practices will be very difficult. Instead, the focus may best be on avoiding losses and retaining existing stocks.[41]

Increasing soil carbon can provide benefits to soil health and improve other environmental outcomes, such as freshwater quality and nutrient retention. Increasing soil carbon stocks will also contribute to mitigating greenhouse gas emissions, but there is not yet sufficient long-term field-scale research to forecast the effects of management practices and the impacts of climate change with acceptable uncertainty.[42]

For all these reasons it will be some time before we can reliably include soil carbon management in climate change mitigation efforts.

The temperature effects of planting new forests

From a climate change mitigation perspective, the aim of planting new forests is to increase carbon storage for the purposes of lowering temperatures. This is sometimes described as 'offsetting' gross emissions of greenhouse gases. For complete offsetting, the temperature effect from planting trees should ideally be equal and opposite to that caused by the emissions being offset.

There are indications that the cooling associated with reforestation in New Zealand may not be as large or last as long as currently anticipated. Removing carbon dioxide from the atmosphere has a cooling effect, but there are other temperature-related effects of changing land use.

A prominent effect concerns changes in the reflectivity or albedo of the land. For example, converting pasture to forest can have a warming effect due to the reduced reflectivity of the land. By contrast, evapotranspiration and cloud cover effects can have a cooling effect. There are also other, less well understood effects such as methane absorption by forest soils that may also have an impact.

This complex and coupled trade-off between decreased albedo (warming) and increased cloud cover (likely cooling) may even cancel each other to some extent. However, even if there is less cooling than anticipated from reforestation, this effect should not be assessed in isolation. In New Zealand, only considering the albedo difference may make pasture seem more attractive than forests (because pasture has a higher albedo, resulting in less warming). But pasture is used for farming ruminant livestock, which are a considerable source of warming.

[41] Biological Emissions Reference Group, 2018, p.38.

[42] Biological Emissions Reference Group, 2018, p.38.

Permanence of land-based carbon stocks

Notwithstanding the uncertain temperature effects of land use changes, there is also the issue of permanence of carbon storage. The time frame carbon needs to be stored so as not to interfere with the climate system is often not appreciated. Indeed, the timescales that need to be considered are daunting. As was detailed in chapter two, some of the fossil carbon released into the atmosphere stays there causing sustained warming for a very long time – hundreds to thousands of years.[43]

Vast social and economic changes have occurred in New Zealand over the last 200 years. Yet it would likely take this long or longer for newly established native forests to reach their maximum carbon storage capacity.[44] This suggests that ensuring permanence from a socio-economic perspective will be challenging without even considering what ongoing climate change might do to the carbon stored on the land.

The consequences of a two degree Celsius rise in the mean global temperature for ecosystems around the world will be significant. Even with the one degree Celsius rise that has already occurred[45] ecosystems are showing signs of stress. But these impacts are not felt uniformly. Climate change impacts differ markedly from region to region.

In North America, increases in summer temperatures, drought and lightning strikes have increased ignition and the extent of fire spread.[46] Increases in minimum winter temperature have prompted the spread of pest insects, as populations are no longer kept in check by what were once deadly cold spells.[47]

In 2016, emissions from insect damage and fire across Canada's 228 million hectares of managed forests were estimated to be equivalent to 98 million tonnes of carbon dioxide – almost five times that sequestered by forest management, making Canada's forests a net source of greenhouse gas.[48]

Rising temperatures and atmospheric carbon dioxide

New Zealand's landscapes currently represent a significant terrestrial carbon sink.[49] But changes projected over coming decades have the potential to tip the balance. To understand how global temperature increases might impact on New Zealand's capacity to store carbon, we have first to gauge what an elevated global temperature might mean for New Zealand's climate and weather patterns, and how this might in turn affect ecosystems.

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[43] The following quote makes this point: "If carbon is to be usefully stored (on land, in the ocean or in geological repositories), it must remain stored not just for 100 years, but for more than 10,000 years." (Mackey et al., 2013, p.556).

[44] Mountain beech in inland Canterbury is estimated to reach maximum biomass at 150 years old, kauri forest in the Auckland region is estimated to take 300 years, while the estimate for mixed broadleaved podocarp forests in south and coastal Otago is 700 years – as presented and cited in Holdaway et al., 2010 (Table 1, p.29).

[45] Ministry for the Environment, 2018b.

[46] Veraverbeke et al., 2017; Allen et al., 2010.

[47] University of Alberta, 2014.

[48] Canada's Greenhouse Inventory in 2016 reports 20 Mt CO_2-e sequestered by forest management and 98 Mt CO_2-e emitted by natural disturbances, a net loss of 78 Mt CO_2-e (UNFCCC, 2016).

[49] Ministry for the Environment, 2018a.

New Zealand's average temperature is projected to rise between 0.7 and 1.0 degrees Celsius above the 1986–2005 baseline by 2040. Beyond that, an increase of up to 3.0 degrees Celsius by 2090 and 3.7 degrees by 2110 is projected under the worst-case scenario where emissions continue to rise. Although temperature increases are expected to be greatest during the summer and autumn periods, they will be observed year round, with decreasing frost frequency and increasing hot days.[50]

Photosynthesis and respiration rates are partly determined by temperature, and an adequate supply of water and nutrients, including carbon dioxide. Predicted temperature rises here in New Zealand, coupled with increased atmospheric carbon dioxide concentrations, have been predicted to lengthen the growing season and increase growth rates for radiata pine trees, as long as water and other nutrients are not limiting.[51]

This fits with the global picture where rising temperature and levels of atmospheric carbon dioxide are predicted to increase primary productivity in temperate forests – although to a lesser extent than in boreal ecosystems.[52]

But this does not present the whole picture, as the ecological impacts of increases in temperature and atmospheric carbon dioxide on ecosystems cannot be considered in isolation from other climate-driven changes that may also occur. It will be the combined impact of all effects that will determine the amount of carbon stored in our forests and farms, for better or worse.

Studies have predicted very different outcomes for the biosphere's capacity to store carbon by the end of the century. Some suggest that increases in temperature and carbon dioxide will increase the size of the sink; others indicate that the biosphere will become a net source of carbon.[53]

Flooding and drought

Projected reductions in New Zealand's annual rainfall will likely lead to more dry days across the north and east of the North Island. Conversely, precipitation is projected to increase in the south of the West Coast region, by up to 40 per cent more rain by 2090 under the worst-case scenario.[54] The extent to which increased rainfall promotes growth depends on the rate and intensity of rainfall events, and the extent to which

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[50] New Zealand's National Institute of Atmosphere and Water (NIWA) downscaled global climate models to examine the changes to climate and weather in New Zealand. Using conditions between 1986 and 2005 as a baseline or reference point, they projected the change New Zealand is likely to see under a range of potential IPCC scenarios.

These included IPCC's most ambitious scenario, RCP2.6, where greenhouse gas (GHG) emissions are not just reduced, but move to a net negative where GHG are actively being removed from the atmosphere. At the other end of the spectrum, RCP8.5 essentially describes a worst-case scenario. Ranges presented indicate the median model output under RCP2.6 and RCP8.5; single values are under RCP8.5 unless specified otherwise. Ministry for the Environment, 2018b.

[51] Kirshbaum et al., 2012.

[52] Reyer, 2015.

[53] Bellassen and Luyssaert, 2014; Reyer et al., 2017.

[54] Uncertainty in New Zealand's projections for precipitation is high: "For a number of regions of New Zealand, there is no clear direction of precipitation change, even at 2090 under RCP8.5. The ensemble-average is often smaller than ±5 per cent, with the model range (the 5th-percentile and 95th-percentile model values) varying between quite large (>10 per cent) decreases and increases." (Ministry for the Environment, 2018b, p.76)

productivity is limited by water availability under current conditions. Small, regular rainfall events are optimal for plant growth.[55]

Rainfall intensity is likely to increase with increasing air temperatures, which could result in flooding and over-saturation of soils. Coupled with projected increases in winter wind speeds throughout the country, soft, wet soils and high winds are predicted to increase the rate of windfall in both native and exotic plantation forests.[56] Likewise, irregular rainfall is also likely to lead to further drought, largely in already drought prone regions.

Source: Ben Rodriguez

Figure 3.11. A rainstorm rolls across the Canterbury Plains. As the atmosphere warms, rainfall patterns are predicted to become more irregular, with some areas experiencing more droughts, while other areas will see more intense rainfall. Both these outcomes will influence the ability to store carbon on land.

Water limitation will slow the rate of growth and alter the rate and capacity for carbon sequestration in regions exposed to increasingly frequent drought. Under more severe water stress, drought can cause irreversible cellular damage resulting in the premature shedding of leaves or branches, or even tree death.[57]

Perhaps of more concern, however, is the risk that dead, dry plant tissues in a forest will significantly increase forest flammability. The number of days per year when conditions are considered to present very high and extreme fire risk is projected to increase under all climate scenarios examined, particularly along the east coasts of both the North and South Islands.[58]

[55] Damp soils provide water to the plant while maintaining the air spaces required for oxygen exchange. Water-saturated soils, however, close these air spaces and limit the available oxygen, thereby reducing respiration rates.

[56] Holdaway et al., 2014b.

[57] Choat et al., 2012.

[58] The frequency of very high and extreme fire risk is projected to increase by an average of 71% across New Zealand by 2040 (Watt et al., 2018).

Pests and pathogens

In addition to stresses imposed by the climate directly on forest health, there are also indirect challenges to forest health. In the first place, a stressed plant is more susceptible to damage caused by pests and pathogens. Secondly, changes to temperature and humidity can favour the reproduction and virulence of pests and pathogens.

Based on the suite of pests and pathogens known to affect radiata pine plantations in New Zealand currently, climate change-induced range shifts are predicted to have minimal effect on sequestration potential.

Risks to plantation and native forests alike can change in ways that are hard to estimate. These include organisms on biosecurity watch lists that have the potential to disturb if they arrive. But beyond that, any organism, native or otherwise, that is benign under current conditions, has the potential to have devastating consequences under changed climate conditions if the balance of ecological interactions is shifted.[59]

The potential for perturbation of carbon stores from climate-driven disturbances does not stop above ground. As a large component of terrestrial carbon is stored in the soil, loss of vegetation exposes the soil to further losses of carbon, whether intentionally through crop harvest or unintentionally through disturbances like fire or extreme weather events.

Erosion, sediments and sea level rise

Once disturbed, carbon can be lost from soils biologically as disturbances aerate the soil and increase the respiration rates of soil communities, and also mechanically as the soils themselves are carried away by heavy rains or strong winds.

Not all of this carbon is lost to the atmosphere, however. As the receiving environment for soils and sediments washed off the landscape, freshwater and coastal wetlands, as well as estuarine and deep ocean sediments, have an important role in storing much of this carbon.[60] Within the tidal zones particularly, the root systems of mangroves and herbaceous saline communities bind sediments and the carbon stored with it.[61]

A rising sea level may force the conversion of low lying coastal land away from pasture or forest as saltwater intrudes on groundwater. Although this has the potential to result in carbon losses, a carefully managed retreat may ultimately allow for an expansion of wetlands and the coastal carbon pool. Moreover, biophysical feedbacks between coastal wetland vegetation and sediment accumulation may allow sediment elevations to rise with the rising sea level thereby allowing wetlands to maintain their current extent.[62,63]

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[59] Watt et al., 2018.

[60] There is limited information for New Zealand, but it has been suggested that on account of New Zealand's rivers being relatively short and steep, more than 80 per cent of eroded carbon may be stabilised in fluvial or marine sediments (Dymond, 2010).

[61] The carbon in biomass and sediments across saltmarsh, mangrove, seagrass and un-vegetated estuarine sediments in Tairua Harbour showed that carbon stocks were highest in stable, long-vegetated sediments (Bulmer and Townsend, 2018).

[62] In the Firth of Thames, increased sediment loads as a result of intensification of land uses through the Waikato have seen an increase in mangrove wetland extent (Lundquist et al., 2017).

[63] Kirwan and Megonigal, 2013.

Evaluating averages versus extremes

On average, the changes projected for New Zealand's climate are relatively small by comparison with other regions of the globe. For many parts of the country, small increases in temperatures and rainfall will at best lead to longer growing seasons and greater productivity. At worst, they could lead to a shift in dominant land use between regions, retreat from low lying coastal regions and saltwater intrusion into aquifers.

Extreme events, such as those with low recurrence cycles – for example, one in 100-year floods, droughts or heatwaves, are predicted with much less certainty than averages. Unfortunately, these are the events that have the greatest potential to perturb ecosystems and result in large, one-off pulse emissions.

As long as ecosystems have the capacity to return to their former state following disturbances, carbon losses will be temporary.[64] Disturbances become a more serious problem if the ecological community is unable to reach its former storage capacity. New Zealand's native forests have positive disturbance feedback loops.[65] Once a perturbation of significant intensity clears mature forests, the species that regenerate first, such as mānuka and kānuka or gorse, have a greater susceptibility to further disturbance, particularly fire.[66] Furthermore, even small changes in climate may pose barriers to the recruitment and re-establishment of mature, wet forest species.

If the average carbon storage capacity of the system is reduced, a permanent loss of carbon from these natural systems ensues. For this reason, any measures taken to increase the carbon storage capacity of a landscape need to ensure that carbon currently stored in it is not placed at risk. Understanding how to maintain and protect the current native forest estate, even as the climate continues to change, is a research priority.

The risks outlined above all point towards forests coming under increasing pressure from climate change impacts, in addition to the already substantial risks they face today. The various threats can also interact in compounding ways, as recent fires in California have shown. Fires fuelled by high wind and low rainfall raced through stands of trees already stressed by drought and disease.

It has been noted that a further one degree Celsius rise in average temperature could see the east coast of New Zealand, from south of Dunedin to the East Cape, in a very high or extreme fire danger zone for up to six months of the year.[67] This signals significantly rising costs of maintaining and managing forests in a warming world.

[64] Even if an ecosystem can eventually return to a similar state, the impact of disturbance may not be trivial.

[65] Perry et al., 2014.

[66] Perry et al. (2012) estimate that in pre-European periods, fires every 15-35 years were sufficient to maintain tussock, scrub, and fernland landscapes.

[67] Wane, 2019.

Conclusion

The history of settlement and habitation in New Zealand has been one of major landscape changes in a relatively short period of time. These changes have resulted in large losses of carbon to the atmosphere, large emissions of biological greenhouse gases and a constantly shifting pattern of carbon capture and loss as land uses continue to change.

As climate policy begins to take effect, the way our land-based carbon stores are managed will need careful consideration. While forests can be long-lived, they cannot be regarded as permanent. Their increasing exposure to climate change impacts further underscores their impermanence. Given the uncertainty that attaches to their temperature effects, a heavy reliance on forest offsets carries risks. As for carbon stored in soil, it appears that it will be some time before we can reliably include its management in climate change mitigation efforts.

4 Emissions reduction targets and climate policy approaches

Key points

- The current approach taken by the international community to setting emissions reduction targets regards all anthropogenic sources and sinks as fully substitutable for one another, though in reality the gases have different impacts on the climate system as well as varying broader environmental impacts.
- The current accounting rules for forestry are based on the assumption that capturing and storing a tonne of carbon dioxide in a tree is of identical value to not emitting a tonne of fossil carbon dioxide.
- The main problems with the current approach are:
  - The temperature outcomes of climate policies are uncertain, because no specific target is set for gross fossil carbon dioxide emissions.
  - Using afforestation to offset fossil carbon dioxide emissions is risky because the carbon stored by trees and other terrestrial ecosystems can be quickly released back into the atmosphere in the event of fires, pests or other disturbances, and the climate benefits of converting land into forest are difficult to estimate accurately.
- An alternative approach that mitigates these problems would be to separate fossil emissions from biological emissions and sinks. This could help to ensure that carbon dioxide emissions from fossil fuel combustion are eliminated as soon as possible.
- In this alternative approach, forests would be used to offset biological emissions, but not fossil carbon dioxide emissions. Forest offsets could be discounted to reflect the impermanence and uncertain temperature effects of reforestation.
- Having a coordinated climate policy approach for farms and forests makes sense because these sources and sinks are often co-produced and co-managed by landowners. Such an approach would promote a more integrated consideration of the competing uses of available land for providing climate change mitigation and other services.

Tackling climate change is a global exercise in managing the risk of dangerous human interference with the climate system in the face of many uncertainties. We do not know what the precise warming response of the Earth's climate, oceans and ecosystems will be to the large quantities of greenhouse gases we are currently emitting into the atmosphere.

We do, however, know that climate change is real and caused by human activities. We also have a sufficient understanding of the relative contribution of each gas to warming to develop emissions reduction targets and climate policies to meet the global temperature goal outlined in the Paris Agreement.

While scientific understanding of the Earth system is continually evolving and targets may need to be reviewed in the light of new knowledge, the physical characteristics of the three main anthropogenic greenhouse gases together with the environmental and economic risks of inaction provide a solid basis for taking concerted climate action today.

The action we take will have consequences for those of us living today and for future generations. Science plays an important role in clarifying the relationship between global emissions pathways and likely global temperature responses. But the ambition of any emissions reduction target and the distribution of costs in meeting it (both within and between generations) is ultimately a political choice rather than one that is scientifically determined.

A solid grasp of the science can help to narrow the space for disagreement. This chapter tries to distil what our understanding of the physical characteristics of carbon dioxide, methane and nitrous oxide means for how emissions reduction targets are constructed and progress towards them measured. It does not broach the economic and social trade-offs that are an essential element of policymaking. These are left to chapter five, which applies the findings of this chapter to the actual circumstances of New Zealand.

The current approach

Since the early 1990s, the approach taken by the international community has been to regard all anthropogenic sources and sinks as fully substitutable for one another. The fundamental assertion underpinning this current approach is that the warming effects of carbon dioxide, methane and nitrous oxide are sufficiently similar that it does not matter which gas is released or where on the planet the emission occurs. In this current approach, the only indicator used to track progress towards targets is the aggregate net total of emissions reaching the atmosphere.

When it comes to tracking progress towards emissions reduction targets, this current approach implies that it does not matter which gas is focused on. The same logic underpins the premise that carbon sequestered and locked up in trees can fully offset the impact of carbon dioxide, methane or nitrous oxide emissions from any source.

As a result, the current approach does not place any particular emphasis on reducing gross emissions of fossil carbon dioxide.

Greenhouse gas metrics

In the current approach, equivalence between the gases is defined using an equivalence metric for greenhouse gases. Many different metrics have been proposed over the years. They are all attempts to distil the different lifetimes, strengths and other characteristics of greenhouse gases into a single number that can be used for setting targets or implementing policies. In effect, these metrics are a bit like exchange rates for currencies.

There is no scientifically objective choice of metric. This is because subjective decisions need to be made about the basis on which the gases are compared, and the 'right' metric to use depends on the goals and values of the users. As a result, the merits and shortcomings of different metrics remain the subject of intense ongoing debate.

A fundamental decision when choosing a metric is the point in the cause-effect chain where the gases are compared – emissions, atmospheric concentrations, the amount of heat trapped, global temperatures or impacts. Metrics based on points higher up the cause-effect chain are more policy-relevant, but also have the highest levels of uncertainty.[1]

Another important choice is the time horizon over which the effects are compared. Metrics based on short time horizons tend to give greater weighting to gases with mostly near-term effects, such as methane. Conversely, metrics based on long time horizons give greater weight to gases with long-term effects, such as carbon dioxide. The choice of time horizon reflects judgments about the relative importance of short, medium and long-term effects, and can change the metric value considerably.[2]

The global warming potential (GWP) metric defines equivalence in terms of the amount of heat trapped (also known as radiative forcing) over a given time period relative to carbon dioxide. For example, assuming a 100-year time horizon, the GWP_{100} for biological methane is 34,[3] which means that a tonne of biological methane released today will trap 34 times more heat than a tonne of carbon dioxide over the next 100 years. While GWP_{100} is relatively simple to use, the correspondence between emissions expressed using GWP_{100} and actual global temperature change is particularly weak for methane due to the shorter duration of its warming effects.

One alternative metric is the global temperature potential (GTP). The GTP metric focuses on the temperature change caused at a specific point in the future by gases released today, rather than the amount of heat trapped. For example, the current

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1 An example of an impact-based metric is the global sea level rise potential and integrated sea level rise potential. See Sterner et al., 2014.

2 For example, the latest estimate of the GWP_{100} for methane is 34, but the GWP_{20} is 86 (including climate-carbon cycle feedbacks). This reflects the comparatively large amount of heat methane traps in the first decade before rapidly decaying. These values are slowly increasing over time as background concentrations change. Source: Ciais et al., 2013, p.714.

3 The value of 34 includes climate-carbon feedbacks. The value excluding these feedbacks is 28.

GTP_{100} of biological methane is four, which means that a tonne of biological methane released in 2019 will increase the global average temperature in the year 2119 four times more than a tonne of carbon dioxide.

Another alternative metric is GWP*. The GWP* metric is based on GTP_{100}, but it defines equivalence between a one-off emission of carbon dioxide and the rate of change of ongoing emissions of methane. It provides a closer correspondence between emissions, radiative forcing and global temperature impacts than GTP_{100}, particularly in the context of setting ambitious emissions reduction targets.[4]

A third alternative metric is the climate change impact potential (CCIP). The CCIP metric balances three different types of impacts on the climate: direct contribution to temperature rise, the rate of warming, and cumulative warming. Compared to GTP_{100}, CCIP metric calculations are more closely based on eventual climate change impacts although the resultant warming potentials for different greenhouse gases are not very different.[5]

In 1997, signatories to the Kyoto Protocol agreed that the GWP_{100} metric would be used to define equivalence for emissions reduction targets and international emission trading under the Protocol. It is likely that the GWP_{100} metric will continue to be used for international reporting and accounting for the foreseeable future, though it has widely recognised shortcomings and its use remains contested.

The attractiveness of allowing full substitutability between sources and sinks lies largely in the way it enables countries to use market-based policy instruments that minimise the cost of meeting emissions reduction targets. This is appealing given the need to make the transition costs of climate policies bearable. It is easier for countries to make early progress in sectors where it is cheapest to do so, thereby winning time to develop solutions for problems that pose more costly adjustments.

While all accounting approaches represent a compromise between reality and pragmatism, the current approach is a particularly crude approximation of what happens in the physical world. The GWP_{100} metric works well enough if the vast majority of a country's emissions are fossil carbon dioxide emissions from energy, transport and industry.

But in countries with large proportions of methane and nitrous oxide in their emissions profiles, the GWP_{100} metric can send the wrong signals. It would be irresponsible to ignore the warming effects of fossil carbon dioxide that continue for centuries to millennia. Neither can we ignore the relatively short-term effects of methane (and, to a lesser extent, nitrous oxide).

[4] Allen et al., 2018.

[5] Kirschbaum, 2014.

International accounting rules for forestry

International accounting rules for forestry were first developed under the Kyoto Protocol. Under these rules, emissions from deforestation are treated as a liability, while new and additional carbon sequestration by forests may be counted towards the achievement of emissions reduction targets. This means capturing and storing a tonne of carbon dioxide equivalent in a tree is regarded as being of identical value to not emitting a tonne of fossil carbon dioxide.

These rules were intended to be conservative by ensuring that only new and additional carbon sequestration resulting from direct human intervention since 1990 could be counted towards emissions reduction targets. These eligible activities represent a subset of the total emissions and removals reported in national greenhouse gas inventories.[6]

There are several reasons why special accounting rules are needed for forestry. First, it is the only sector where significant quantities of carbon dioxide are removed from the atmosphere by sinks. Second, the rates of carbon uptake and release from these terrestrial carbon pools are subject to significant non-anthropogenic impacts such as natural regeneration and natural disturbances (fires, pests and diseases, for instance), in addition to indirect human impacts such as climatic change and carbon dioxide fertilisation effects. Isolating anthropogenic effects from natural ones will become increasingly tricky as the impacts of climate change become more pronounced. Third, there are often strong legacy effects that mean countries risk being rewarded or punished for past forest management decisions, or being credited for carbon sequestration that would have occurred anyway without further human intervention.[7]

As a result of these special features, the accounting rules for forestry are highly complex. There are also substantial differences between the way carbon in the landscape is accounted for under various international and domestic systems.

Problems with the current approach

There are two main problems with the current approach:

- First, the temperature outcomes of climate policies are uncertain because no specific target is set for gross fossil carbon dioxide emissions. This raises the risk that emissions reductions of methane or nitrous oxide can be substituted for action on reducing fossil carbon dioxide. Thus, scenarios in which gross fossil emissions stay high remain a possibility.
- Second, the fossil carbon dioxide emitted into the atmosphere has a warming effect for centuries to millennia. By contrast, the carbon stored by trees and other terrestrial ecosystems can be quickly released back into the atmosphere

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[6] The relevant forestry activities under the second commitment period of the Kyoto Protocol are afforestation, reforestation (planting trees on land that was previously forest) and forest management (management of existing forests planted before 1990 that results in changes in carbon sequestration rates relative to a forest management reference level). Other additional elective activities under the Kyoto Protocol were revegetation, cropland management, grazing land management, and wetland drainage and rewetting, which New Zealand has elected not to account for.

[7] Estrada et al., 2014, p.5.

in the event of fires, pests or other disturbances. Further, the climate benefits of converting land into forest are likely to be less than expected in many cases due to the net effect of albedo changes, hydrological cycle changes and other secondary temperature effects. Continuing to emit fossil carbon dioxide on the basis that an equivalent amount of carbon is being sequestered by biological sinks therefore carries significant risks.

The first of these problems arises because carbon dioxide, methane and nitrous oxide have different properties and warming effects that cannot be easily compared. The current approach attempts to condense these various differences down into a single number for each gas – its GWP_{100} value. But doing this hides the very different risks that each gas poses to the climate system over the coming centuries. Table 4.1 summarises the relevant differences between each gas.

Table 4.1. Relevant characteristics of carbon dioxide, methane and nitrous oxide.

Characteristic	Carbon dioxide	Methane	Nitrous oxide
Atmospheric concentration and recent trend[8]	405 ppm in 2017 (~45% above pre-industrial level), rising at around 2–3 ppm per year (0.5–0.9% per year)	1.85 ppm in 2017 (~150% above pre-industrial level), rising at around 0.006–0.010 ppm per year (0.3–0.6% per year)	0.33 ppm in 2017 (~20% above pre-industrial level), rising at around 0.0008–0.0011 ppm per year (0.2–0.3% per year)
Contribution to radiative forcing between 1750 and 2011[9]	1.82 W/m^2	0.48 W/m^2	0.17 W/m^2
Lifetime/decay function of emissions	Complex decay function; about half is sequestered by oceans and terrestrial sinks within decades, but a small fraction remains in the atmosphere for thousands of years[10]	Decay function approximately resembles an exponential decay curve; about two thirds is broken down within ~12 years[11]	Decay function approximately resembles an exponential decay curve; about two thirds is broken down within ~120 years

[8] NOAA Earth System Research Laboratory. 2019a. *Global Monitoring Division data archive*. https://www.esrl.noaa.gov/gmd/dv/ftpdata.html [accessed 5 March 2019].

[9] Values from Myhre et al., 2013, p.661. Radiative forcing is a measure of the capacity of a greenhouse gas to cause warming by changing the energy balance of the Earth. It is measured in units of watts per square metre (W/m^2).

[10] Ciais et al., 2013, pp.472-473.

[11] This is the 'perturbation lifetime' of methane. The mean time one molecule of methane stays in the atmosphere after being emitted is around 9 years (known as the 'turnover time'). Ciais et al., 2013, p.509.

Characteristic	Carbon dioxide	Methane	Nitrous oxide
Strength and duration of temperature response	Relatively weak but persistent warming; causes climate-carbon cycle feedbacks; long lag time between changes in emissions and temperature response	Strong direct warming; long tail of weak indirect warming caused by degradation products and climate-carbon cycle feedbacks; short lag time between changes in emissions and temperature response	Very strong direct warming; long tail of weak indirect warming caused by climate-carbon cycle feedbacks; medium lag time between changes in emissions and temperature response
Biogeochemical cycles	Fossil carbon dioxide (CO_2 from burning fossil fuels) within slow geological carbon cycle Biological carbon dioxide (CO_2 from forests and land use change) within fast biological carbon cycle	Fossil methane within slow geological carbon cycle Biological methane within fast biological carbon cycle	Nitrogen cycle (N_2O is a by-product of incomplete denitrification)
Wider environmental impacts other than climate change	Causes ocean acidification; increases stratospheric ozone;[12] burning fossil fuels can also contribute to air pollution	Increases stratospheric ozone; farming livestock also contributes to air and water pollution	Decreases stratospheric ozone; fertiliser use and farming livestock also contribute to air and water pollution

The risk of not reducing fossil carbon dioxide emissions

The strength and duration of the warming effect caused by each gas is important from a target setting and climate policy perspective. The atmospheric concentrations of the three main anthropogenic greenhouse gases are currently rising. Methane has risen the most since pre-industrial levels in relative terms. But methane is still at least 200 times less abundant in the atmosphere than carbon dioxide. Nitrous oxide is less abundant again – over 1,000 times less than carbon dioxide.

Given its relatively high abundance, carbon dioxide is the main driver of warming since pre-industrial times and currently traps significantly more heat than methane or nitrous oxide. Not taking strong action on fossil carbon dioxide exposes us to potentially catastrophic risks. This is because the global average temperature will not peak at any level until the atmospheric concentration of carbon dioxide stops rising. Emitting carbon dioxide is, therefore, like turning up a thermostat that cannot easily be turned down.[13] Furthermore, compared to biological emissions, fossil carbon dioxide often has more cost-effective abatement opportunities.

[12] Increases in carbon dioxide and methane are expected to increase stratospheric ozone levels towards the end of the century, particularly in areas outside the tropics. See Butler et al., 2016.

[13] Pierrehumbert, 2010.

The implication of these points for target-setting is that reducing the concentration of carbon dioxide in the atmosphere should be the top priority for tackling climate change at the global level. But the current approach provides no certainty that these risks will be avoided, because it does not specify which gases are to be reduced or when.

Methane has a strong, but relatively short, warming effect.[14] Most of the warming occurs in the first decade or two after emission and less warming occurs once the methane molecules have decayed. This means that if emissions of methane are held constant, after a few decades their warming effect will begin to level off, but not to zero, all else being equal.

Nitrous oxide causes the strongest warming of all three gases on a tonne-for-tonne basis. The warming caused by the emission of one tonne of nitrous oxide resembles that of 298 tonnes of carbon dioxide for the first 100 years.[15] Beyond the first 100 years, however, their warming functions begin to diverge. From a longer-term perspective, the duration of the warming effect caused by nitrous oxide is much shorter than the effect of carbon dioxide (figure 4.1).

Figure 4.1. Global temperature effects of one-off emissions of carbon dioxide, methane and nitrous oxide released in year zero.[16]

[14]The warming caused by a greenhouse gas does not increase linearly as its atmospheric concentration increases; the warming effect saturates and starts levelling off. Therefore adding one tonne of a trace greenhouse gas (such as methane or nitrous oxide) causes more additional warming than adding one tonne of carbon dioxide.

[15]The value of 298 includes climate-carbon cycle feedbacks. Source: Ciais et al., 2013, p.714.

[16]The quantities shown were selected because 298 tonnes of carbon dioxide, 9 tonnes of methane and 1 tonne of nitrous oxide trap the same amount of heat over a 100-year period. These temperature response functions were estimated using the MAGICC climate model, assuming background concentrations of each gas are held constant at current levels and including the impacts of climate-carbon cycle feedbacks. See Reisinger, 2018.

Reducing global methane and nitrous oxide emissions can help to reduce the peak global temperature reached, delay the time at which this peak occurs and lower the rate of warming – but only if global emissions of fossil carbon dioxide are reduced to zero by the second half of the century.

Action on methane and nitrous oxide must be regarded as additional to, not a substitute for, action on carbon dioxide. This is because the warming effects of carbon dioxide are long-lived and unless large reductions in carbon dioxide emissions are achieved, efforts to reduce methane and nitrous oxide will be of limited long-term value.

The risk of relying on biological sinks to offset fossil carbon dioxide emissions

For carbon sequestration by forests, soils and other terrestrial ecosystems to offset emissions and count towards emissions reduction targets in a meaningful way, there needs to be some alignment between the ability of these sinks to mitigate warming and the warming effect caused by emissions.[17]

As outlined in chapter two, fossil carbon dioxide emissions are part of the slow geological carbon cycle. Carbon dioxide emissions and removals by forests and other terrestrial ecosystems are part of the fast biological carbon cycle.

The vastly different speeds of processes in these biogeochemical cycles have important implications for the use of carbon sequestration by forests and other terrestrial ecosystems to help meet emissions reduction targets for fossil carbon dioxide emissions. The sedimentation processes that gradually convert buried organic matter into fossil fuels are very slow. When fossil fuels are burnt, some of the carbon released stays in the atmosphere for a very long time. By contrast, carbon is continually being rapidly exchanged between the atmosphere and the biosphere via photosynthesis and respiration processes.

The storage capacity of terrestrial carbon pools is uncertain, but likely diminishing.[18] The quantity of carbon that could be returned to forests, soils and other depleted terrestrial ecosystems in the near future is likely to be less than the quantity that has been released from these pools since pre-human times. This is due to irreversible changes to the carbon storage capacity of terrestrial ecosystems (including biodiversity loss) caused by human activity, as well as both physical and economic constraints on the availability of suitable land.

Forests usually store more carbon than pasture or grassland in both above-ground biomass and the soil. Any forest, even one managed for continuous cover, will eventually reach a steady state and the quantity of carbon stored will level off. It then becomes a reservoir of carbon for as long as the forest remains standing and healthy.

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[17] The impact of trees on the climate is complex and is an active area of scientific research. Trees emit a large range of chemicals, some of which cause warming while others may cause cooling. Trees can also change the albedo (reflectivity) of the Earth's surface, which alters how much incoming solar radiation is reflected back into space.

[18] Green et al., 2019.

The Intergovernmental Panel on Climate Change (IPCC) succinctly states that: "Biogenic storage is not as permanent as emission reductions by geological storage."[19] Land use change is reversible, though not necessarily easy. To offset fossil carbon dioxide emissions, sequestered carbon would need to remain safely stored in terrestrial carbon pools for very long periods of time. Institutional mechanisms would be needed that can reliably lock in land use for centuries into the future, or at least until negative emissions technologies (other than forests) have been deployed at a commercial scale.[20]

The extent to which biologically sequestered carbon can mitigate warming is uncertain and likely to become more so. Even if we could guarantee the maintenance of forests and other terrestrial carbon pools over very long periods (and we have no working models for doing this), climate change is likely to increase the frequency and magnitude of carbon dioxide releases from these carbon pools due to increased disturbances such as disease, drought, storms and fires. Simply managing and maintaining the carbon already stored in the landscape may turn out to be a major challenge as the impacts of climate change intensify, let alone storing more of it.

Higher average temperatures and carbon dioxide fertilisation effects are likely to increase the rates at which forests and pastures sequester carbon. While this could provide a short-term advantage in some parts of the world, climate change is likely to make living stores of carbon increasingly volatile. Though knowledge and technology for predicting and managing these risks will no doubt improve, enhancing the resilience of carbon pools to droughts, fires and other extreme weather events is likely to become more difficult.

This misalignment between the near-permanent warming effects caused by fossil carbon dioxide emissions, and the volatile and potentially unstable mitigating effects of terrestrial carbon sinks, suggests that using carbon sequestration by trees to offset fossil carbon dioxide emissions comes with genuine risks.[21]

Emissions reduction targets should reflect durable outcomes that bequeath manageable risks to future generations. Offsetting fossil carbon dioxide emissions with forest sinks is unlikely to achieve this.

On the other hand, using terrestrial carbon sinks such as forests to offset biological emissions leads to a better alignment of risks. Forests cannot sequester significant quantities of methane or nitrous oxide directly from the atmosphere.[22] But if the purpose of offsetting is to mitigate the warming impact of emissions by creating a roughly equal but opposite impact on global average temperature, then forests can

[19] de Coninck et al., 2018, p.343.

[20] A variety of negative emissions technologies are being developed that have the potential to artificially remove carbon dioxide from the atmosphere and store it more permanently than forests. In addition, institutional mechanisms will be needed to not reverse any reductions in fossil emissions (e.g. by reopening oil and coal fields).

[21] Mackey et al., 2013.

[22] Methanotrophs in soils can remove atmospheric methane by converting it to other organic compounds and eventually to carbon dioxide, but are a much smaller sink than tropospheric hydroxyl radicals.

do that over a timescale that matches more closely the warming effects of biological emissions.

Different types of forests will deliver climate benefits over different time frames. When a new plantation forest is planted, it rapidly sequesters carbon until the first stands are harvested. After that, the amount of carbon stored resembles a 'saw tooth' trend as the forest enters a continuous cycle of regrowth, harvest, regrowth and so on.

The average amount of carbon stored by a plantation forest levels off and remains approximately constant after the first harvest. Though not identical, this is similar to the way that the warming effect from a constant rate of methane emissions begins to level off after a few decades.

In the case of a slow-growing native forest, the carbon sequestration rate would be initially lower than a fast-growing plantation forest. If the native trees are not harvested, the amount of carbon stored (and hence the contribution to reduced warming from sequestration) would later surpass that of a plantation forest and continue to rise for centuries before eventually levelling off as the forest reaches a mature steady state.

The carbon stored in a native forest is generally more resilient to climate change impacts than a plantation forest, given the likely higher diversity of species within it. The time frame of the climate benefit provided is similar to the duration of the warming effect of a constant rate of nitrous oxide emissions, which levels off after a few centuries.

A lag time would be expected between carbon sequestration by a forest sink and the resulting effect on global average temperature due to inertia in the climate system. However, the extent to which planting forests can mitigate warming is not simply a matter of how much carbon is removed from the atmosphere. In addition to sequestering carbon, converting land to forest also changes the reflectivity or albedo of the Earth's surface, as well as local water vapour levels and low-level cloud formation patterns.

The net impact of these other factors can diminish the climate benefits of forest sinks, though the extent of these effects is uncertain. Faced with these uncertainties, some level of reduction in gross biological emissions will be a necessary part of managing climate risks.

Figure 4.2 is a simplified conceptual diagram that illustrates the mismatch between the temperature effects of forest sinks and fossil carbon dioxide emissions, and the closer alignment of forest sinks with biological emissions.

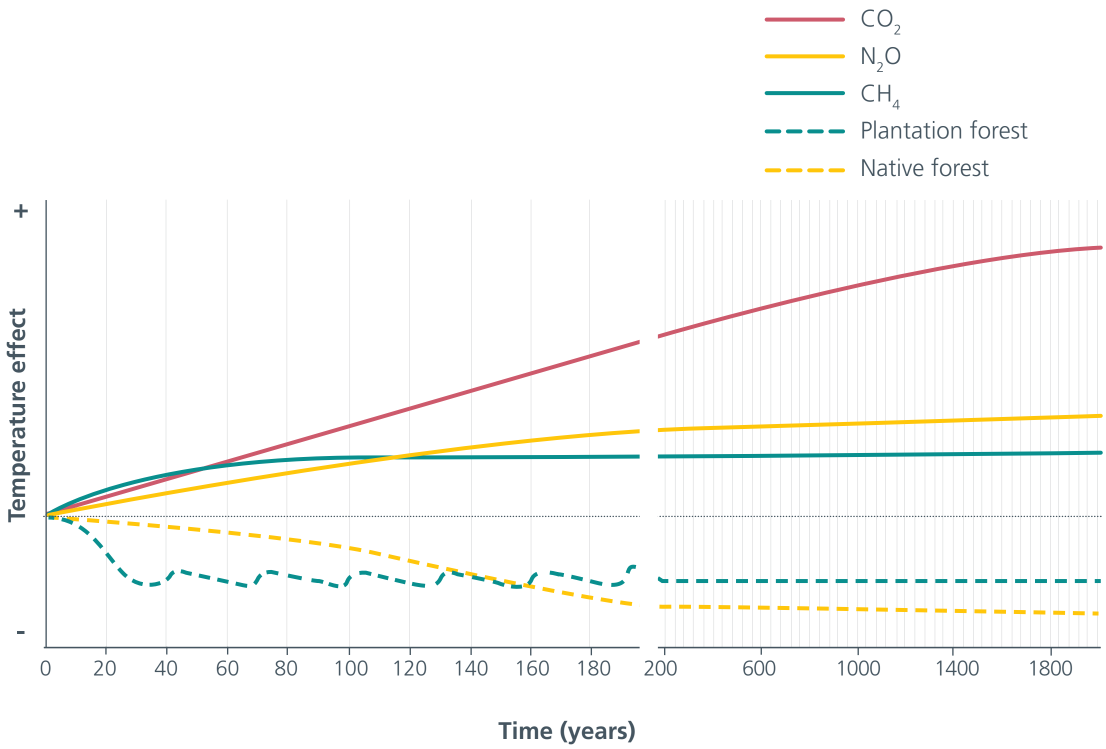

Figure 4.2. Comparing the warming effects of a constant rate of methane, nitrous oxide and carbon dioxide emissions with the likely temperature effects of a plantation forest and a native forest.[23]

The risk of focusing too narrowly on climate policy alone

In addition to the main problems outlined above, the current approach also perpetuates a fragmented approach to environmental policymaking. Separate, parallel policy frameworks have been established for dealing with climate, biodiversity, air quality, water quality and other environmental issues.

As a result, policies to tackle the three main anthropogenic greenhouse gases have been developed with a singular focus on their heat-trapping properties. But in reality, these gases and the activities that give rise to them have a wide variety of impacts on air, water, soils and ecosystems.

For example, excess carbon dioxide causes ocean acidification, which damages ocean-dwelling plants and animals. Burning fossil fuels can also contribute to air pollution. Nitrous oxide is an ozone-depleting substance. The activities that give rise to nitrous oxide emissions can also lead to excessive levels of reactive nitrogen being released into the environment, which can cause eutrophication of waterbodies and air pollution.

[23] To offset the warming from a constant rate of emissions, the carbon stock in a forest needs to be maintained for centuries to millennia. This may become increasingly difficult because, while carbon dioxide fertilisation effects could increase forest growth rates, droughts, diseases and extreme weather events are likely to increase the risk of future losses from terrestrial carbon pools.

These different environmental impacts need to be managed in a more integrated manner. Treating all sources and sinks as fully substitutable for policy purposes may not always support integrated environmental management. For example, by permitting action on gross fossil carbon dioxide emissions to be delayed, the current approach risks exacerbating the problem of ocean acidification.

An alternative approach: Separating fossil emissions from biological sources and sinks

The analysis above suggests that separate emissions reduction targets should be set for carbon dioxide, methane and nitrous oxide because this would provide the greatest clarity regarding their temperature and other environmental impacts. However, setting up three new policy instruments – one for each gas – could carry significant transaction costs.

Biological methane and nitrous oxide are generally co-produced, and biological sources and sinks are often co-managed by landowners. Having a coordinated policy approach to managing them therefore makes good economic sense, especially in countries with high shares of biological emissions in their emissions profiles.

Treating fossil carbon emissions separately from biological sources and sinks of carbon dioxide, methane and nitrous oxide would help mitigate the main problems of the current approach. This alternative approach would be based on the fact that fossil carbon dioxide and fossil methane are part of the slow geological carbon cycle, while biological methane, nitrous oxide and carbon dioxide emissions from forests, soils and other terrestrial ecosystems are part of fast biological cycles.

In this alternative approach, two separate targets would be set for fossil emissions and biological sources and sinks. Setting a separate target for fossil carbon dioxide would reflect the particular risk that this gas poses to our long-term ability to influence the global climate.

The alternative approach outlined here clearly differs from grouping together carbon dioxide and nitrous oxide as 'long-lived' gases and tackling methane separately as a 'short-lived' gas. That categorisation is somewhat arbitrary, since whether nitrous oxide should be considered a short or long-lived gas depends on the time horizon chosen.

Setting a target for fossil emissions

To keep the increase in global average temperature to well below two degrees Celsius, carbon dioxide emissions will need to be eliminated. This is because the global average temperature will only start to level off once the atmospheric concentration of carbon dioxide stops rising.[24] If there is a need for any ongoing emissions, these will need to be compensated for by negative emissions technologies that remove an equivalent amount of carbon dioxide out of the atmosphere permanently.

[24]Even once carbon dioxide emissions are halted, past emissions will leave behind a warming impact for centuries to come.

The alternative approach seeks to face this reality directly by proposing a target of zero emissions of fossil carbon dioxide and fossil methane by a target year in the second half of the century. This target is consistent with the goal of ensuring that the global average temperature will eventually peak at some level. How much warming fossil carbon dioxide causes will depend on the target year and how much is emitted cumulatively between now and then.

Emissions and removals of biological carbon dioxide from forestry and land use change would not be counted towards this target, due to their non-permanent nature. The removal of access to forest sinks would send a strong signal that action to eliminate carbon dioxide emissions from fossil fuel combustion – the main driver of climate change to date – can no longer be delayed. Such a target would require an immediate start to ongoing and progressively deeper cuts to gross fossil emissions.

Afforestation is the only carbon sequestration option currently available at scale. But other ways of sequestering and storing carbon might become available in the future, such as bioenergy with carbon capture and storage (BECCS)[25] and technologies that can directly capture carbon dioxide from the air. These technologies are still at the early stages of development. But if they become scalable and commercially viable, they might be counted towards targets for fossil emissions – so long as they can provide a more permanent and reliable method of storing carbon than trees, soils and other terrestrial ecosystems.

In their absence, the only way to achieve a balance between fossil emissions and removals without relying on temporary carbon storage by forests is to reduce gross fossil emissions to zero. This is why achieving deep and rapid reductions in fossil carbon dioxide emissions must be a top priority for all countries.

Fossil methane would also be included in targets for fossil carbon dioxide, since it represents an injection of carbon from the slow geological carbon cycle into the atmosphere. When fossil methane decays it adds a small amount of carbon dioxide to the atmosphere that was not there previously – unlike biological methane, where the carbon dioxide produced is part of the fast biological carbon cycle.

Setting a target for biological emissions

In addition to reducing fossil carbon dioxide emissions to zero, methane and nitrous oxide emissions need to be reduced to keep the rise in global average temperature to well below two degrees Celsius. The level of emissions reduction targets for gross methane and nitrous oxide emissions would be determined by the extent to which a country intends to contribute to the global mitigation effort, and the relative abatement costs of methane and nitrous oxide.

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[25]BECCS is a variant of carbon capture and storage that combines carbon sequestration by trees with geological storage of carbon dioxide. BECCS would still require considerable amounts of land and this may place constraints on its use in some countries.

Unlike fossil carbon dioxide, nearly all methane is removed from the atmosphere by rapid natural processes. This means that so long as the atmosphere's capacity to neutralise methane is maintained, methane emissions need to be reduced but not necessarily all the way to zero – *if* the aim is to stabilise the contribution to warming from methane at a target level.

Nitrous oxide has a longer lifetime than methane, resulting in a longer lag time between nitrous oxide emission reductions, changes in the atmospheric concentration of nitrous oxide, and the global temperature response. But over long time frames the warming contribution from constant nitrous oxide emissions would also eventually level off, as it does for methane.

While a lot of research has been done on emissions pathways for carbon dioxide, there has been far less research and debate in the global community to date regarding emissions pathways for methane and nitrous oxide. So long as we continue to produce food, there is likely to be some low level of residual biological emissions from agriculture. This is because any food production, no matter how efficient, will result in some biological emissions.[26]

The IPCC recently concluded that a 35 per cent or more reduction in global fossil and biological methane emissions by 2050 relative to a 2010 baseline, and comparable reductions in global nitrous oxide emissions (in addition to 100 per cent reductions of carbon dioxide emissions), would be compatible with meeting a 1.5 degree Celsius temperature objective.[27]

Importantly, this 35 per cent or more figure for methane refers to all sources of methane, not only biological methane. The majority of these emissions reductions came from fossil methane, which is generally cheaper to abate than biological methane.[28] The extent to which these modelling results provide a suitable benchmark for a country's emissions reduction target for methane therefore depends on how much of that methane comes from biological rather than fossil sources.

In the alternative approach, emissions and removals by forestry and other land use change would be counted towards the biological emissions reduction target.[29] Though there would be better alignment between the duration of temperature effects of biological sources and sinks, heavy reliance on forestry offsets would still remain somewhat risky given their non-permanent nature and uncertain temperature effects.

[26] Grains, fruits, vegetables and non-ruminant livestock (e.g. fish, pork), while resulting in lower greenhouse gas impacts than ruminant livestock (e.g. sheep), still produce emissions (Clune et al., 2017).

[27] Intergovernmental Panel on Climate Change, 2018b, p.16.

[28] The IPCC report estimated that reductions in global agricultural methane emissions of between 24 and 47 per cent would be compatible with meeting a 1.5 degree Celsius temperature objective. The models used for this assessment had limited options for reducing gross biological emissions. Measures such as improved agricultural management (including better livestock breeding and improved feeding practices), improved use of nitrogen fertilisers, improved manure management, and dietary changes were included. But other measures such as methane inhibitors and vaccines in livestock, synthetic proteins and nitrification inhibitors were not modelled. This means that opportunities for biological emissions reductions might be able to play a larger role than has been recognised to date.

[29] If the forest estate were a net carbon sink, this would provide an opportunity to offset gross biological methane and nitrous oxide emissions. Conversely, if it were a net source, forestry would represent an additional emissions liability.

For these reasons, a discounting factor could be applied to forest offsets to reflect the fact that the warming effect caused by biological methane and nitrous oxide is known with greater certainty than the temperature effects of forest sinks. That is, more than one unit of carbon sequestered from trees would be required to offset each unit of biological emissions. Such a discounting factor could be based on the level of risk of re-release of carbon stored in forests, the albedo effect and other secondary temperature effects.

Regardless of the level of ambition of the targets chosen, the rationale behind the choice of national emissions reduction targets and their expected economic and temperature impacts should be made clear and explicit. If there are reasons why the temperature objectives and emissions reduction targets for fossil emissions and biological emissions are different, these should also be clearly stated.

The role of metrics in the alternative approach

In the alternative approach, a metric is still needed to define equivalence between fossil carbon dioxide and fossil methane emissions, as well as between biological emissions and carbon sequestration by forest sinks. Which metric would be best for this purpose remains an open question.

The alternative approach outlined would mitigate some of the concerns around current use of the GWP_{100} metric. When greenhouses gases are bundled together using the GWP_{100} metric, it becomes unclear what proportion of emissions reductions will be achieved through reducing fossil carbon dioxide emissions and what proportion will be achieved through reducing other gases, such as nitrous oxide and methane. This means the impact of emissions reduction targets on global temperature becomes more uncertain, because the temperature effect depends on which gases are reduced and when.

If a separate emissions reduction target is set to achieve zero emissions of fossil carbon dioxide and fossil methane by a given date, this removes the risk of delaying action to reduce fossil emissions. Thus, the main shortcomings of GWP_{100} – that it fails to capture the very long-term warming effects of fossil carbon dioxide that continue to occur after 100 years, and risks substituting action to reduce fossil emissions with action to reduce biological emissions – are avoided.

The GWP_{100} metric also has the advantage of being simple to use and familiar. No conversion would be needed between domestic policy and international reporting obligations. However, there would remain a mismatch between emissions, removals and temperature outcomes, particularly with respect to the number of trees that would need to be planted to offset methane and nitrous oxide emissions.[30]

[30] This assumes only the carbon sequestration benefits of forestry are considered. The total temperature impact of forests would likely be less than expected due to the net effect of albedo changes, hydrological cycle changes and emissions of other trace greenhouse gases by trees.

The GWP* metric would provide a closer correlation between emissions, removals and temperature outcomes. Using GWP* instead of GWP_{100} would result in fewer trees being planted each year to offset biological emissions, all else being equal. As a result, there would be a better alignment between the temperature effects of afforestation and the warming effects from ongoing methane and nitrous oxide emissions.

Though GWP* could be used for the alternative approach, the decision of whether or not to use it is most relevant for the current approach. This is because, by treating fossil carbon dioxide completely separately, the alternative approach at least partially avoids some of the problems associated with GWP_{100}.

It should be stressed that the metric a country chooses to frame its emissions reduction targets and domestic climate policies does not have to be the same as that used to fulfil international reporting and accounting obligations. One can be converted into the other. The fact that the rest of the world sticks with a less than satisfactory metric is not a reason to be steered by it domestically.

5

Implications in the New Zealand context

Key points

- New Zealand's approach to climate policy treats all sources and sinks as fully substitutable, and carbon sequestration by forests as being of equal mitigation value to reducing gross fossil emissions.
- New Zealand has based its current approach to climate policy on the premise that it provides the least costly way to achieve emissions reductions.
- To understand how the alternative approach described in chapter four might differ from the current approach in the New Zealand context, modelling work was undertaken. Modelling indicates the emissions price for fossil emissions would be higher under the alternative approach than the current approach, but the emissions price for biological emissions would be lower.
- The biggest land use change predicted under either climate policy approach is the shift from sheep and beef farming to forestry, but the alternative approach results in far fewer trees to reach its targets by 2075 compared to the current approach.
- New Zealand policymakers must decide whether they want to store carbon as forests over large areas of Aotearoa New Zealand, or take a more ambitious approach to reducing fossil emissions.

Chapter four questioned the wisdom of treating all sources and sinks as fully substitutable, however convenient this may be for minimising the cost of meeting emissions reduction targets. In particular, it has drawn attention to the very different risks the three main anthropogenic greenhouse gases pose over different time frames.

While carbon dioxide emissions from burning fossil fuels need to be reduced to zero, the same does not necessarily apply to biological emissions – although they certainly need to be minimised. The previous chapter also questioned the wisdom of offsetting long-lived fossil carbon dioxide emissions with forest sinks whose permanence cannot be guaranteed.

An alternative way forward was proposed that separates the treatment of fossil emissions from the management of biological sources and sinks.

Chapter five applies this lens to New Zealand's current approach to climate policy and then considers what the alternative approach proposed might entail.

New Zealand's current approach

New Zealand has made full use of the flexibility that successive negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) have made available to countries seeking to chart a path to lower emissions. In particular, our climate policy approach has featured economy-wide emissions reduction targets that cover all sectors and all gases, and has made full use of forest sinks.

This flexibility has been particularly attractive given New Zealand's emissions profile, which is unusual for an industrialised economy. The challenge for most other comparable countries is to replace fossil fuels as the energy base of their economies, and to drive down process emissions from heavy industries like steel and cement.

New Zealand shares this problem – it has a steel mill, a cement producer and a growing transport sector that is vital for domestic and international commerce. But electricity is generated largely from low-emissions sources thanks to large investments in hydropower and geothermal power following the Second World War and, more recently, wind power.

Many of the relatively cheap options in other countries for mitigating fossil emissions from the energy sector, such as substituting renewable energy for fossil fuel combustion, have already been adopted in New Zealand. However, fossil emissions from transport and industry are still significant and rising, so strong action to reduce these emissions remains a priority.

What sets New Zealand apart from other industrialised countries is that roughly half of our total gross emissions are biological emissions from agriculture if GWP_{100} is used. At present there are no easy technological fixes for reducing biological emissions significantly.

For these reasons, New Zealand has long argued that it faces a higher cost of emissions abatement than most other comparable countries. This has driven the case for maximum flexibility in its climate policy, with heavy reliance on both forest sinks and international units.

Since 2008, the central climate policy instrument used to meet New Zealand's domestic emissions reduction targets has been the New Zealand Emissions Trading Scheme (NZ ETS). The NZ ETS was designed from the outset to accommodate all gases and all sectors, including forestry and agriculture.

In practice, emissions-intensive and trade-exposed (EITE) sectors were protected through free allocations or, in the case of agriculture, by having their compliance obligations suspended. But from a design point of view, it has always been intended that full compliance obligations would eventually be extended to all sectors by phasing out free allocations.

The accounting provisions negotiated under the Kyoto Protocol have heavily influenced New Zealand's domestic climate policy approach and the design of the NZ ETS. It has seemed logical that if the accounting rules under the Kyoto Protocol treat all gases as substitutable, and cover all sectors, including emissions and removals from forests, then New Zealand's domestic emissions reduction targets and the NZ ETS should do the same.

Few countries have aligned their domestic climate policy approach to the international accounting rules under the Kyoto Protocol as closely as New Zealand has. In particular, no emissions trading scheme other than the NZ ETS has mandatory inclusion of emissions and removals from forestry. In the European Union (EU), for example, forestry has been kept firmly at arm's length from the EU ETS, with separate policies developed for ETS sectors, non-ETS sectors and forestry as part of the EU's 2030 Climate and Energy Framework.[1]

[1] Limited use of offsets from forestry and other offsetting projects are permitted in the California ETS, the Regional Greenhouse Gas Initiative in the north-eastern United States, the Saitama ETS in Japan, the Beijing pilot ETS, the Fujian pilot ETS, and the Hubei pilot ETS in China (ICAP, 2018).

Source: Parliamentary Commissioner for the Environment archives

Figure 5.1. A vast and complex system of rules has been developed for calculating the carbon stored in vegetation. In New Zealand, forests planted since 1990 are eligible for emission units, while forests established prior to 1989 are not. Regenerating scrub such as this mānuka in the Coromandel may or may not count as sequestration, depending on when the land was cleared and when reversion started.

New Zealand's adoption of the current approach is based on the premise that it provides the least costly way to achieve emissions reductions. In theory it enables the NZ ETS to have the highest possible number of participants, ensuring a large, liquid market with a high trading volume (if compliance obligations are fully extended to all sectors). Having a large number of participants also helps make the system more resilient to economic shocks. Providing industries with a cheap way to offset their emissions using forestry and a generous allowance for international units has alleviated concerns regarding international competitiveness and the potential for emissions leakage.

Extending compliance obligations under the NZ ETS to the agricultural sector would add to market liquidity and incur relatively low set-up costs. The institutional infrastructure of the NZ ETS is largely developed and a reporting system has already been established for all sectors.

But as chapter four explained, fossil carbon dioxide emissions disrupt the global climate system in different ways to biological emissions and removals. An emissions reduction target that covers all gases from all sectors means the expected long-term temperature outcome of New Zealand's emissions profile is uncertain given the significant amounts of biological methane and nitrous oxide it contains. Being indifferent about which gases are reduced and when, ignores the long-term warming effects of carbon dioxide that persist over timescales that span centuries.

The risks of pumping fossil carbon dioxide into the atmosphere on the basis that an equivalent amount of carbon has been sequestered in a forest sink whose permanence cannot be guaranteed are clearly very different from eliminating the same gross emissions in the first place. For these reasons, continuing to regard all anthropogenic sources and sinks as fully substitutable is questionable, even if it is allowed under international accounting rules.

Furthermore, the current approach is not designed to meet any environmental outcomes other than reducing total aggregate net emissions of greenhouse gases by a target year. Even if a perfect pricing instrument with no exemptions had been implemented in New Zealand as originally intended, the current approach to accounting that is used to demonstrate progress towards domestic emissions reduction targets would continue to conceal significant environmental and economic risks. The current approach is probably only least cost if 2050 is considered as the end point, the costs of action beyond that point are ignored and no other environmental impacts are taken into account.

While the short-term costs of relying heavily on forest offsets may be lower, it may be at the cost of delaying serious climate action on reducing gross emissions. Relatively cheap forest offsets would be expected to suppress the emissions price. And if they did, there would likely be less investment in innovation and the development of new abatement technologies to reduce gross emissions. Yet there is empirical evidence that innovation activity in low-emissions technologies increases with emissions pricing.[2]

International evidence also indicates that these low-emissions technologies spurred by emissions pricing generate knowledge spillovers to other local sectors and are of relatively high economic value compared to conventional technologies.[3] These findings may provide a positive competitive advantage, dampen concerns around international competitiveness and indicate a "channel for positive home country effects from unilateral policies."[4]

The extensive use of forest sinks enables New Zealand's climate performance, at least from an accounting point of view, to be cast in a positive light. New Zealand's gross emissions increased by nearly 20 per cent between 1990 and 2016. Yet despite these increases in gross emissions, New Zealand remains on track not just to meet, but to over-achieve its 2020 target of a five per cent emissions reduction. This is because new and additional carbon sequestration by forests can be counted towards this target (including sequestration from trees planted during the forest planting boom in the 1990s), as well as a considerable surplus of units left over from the first commitment period of the Kyoto Protocol.

[2] Calel and Dechezleprêtre, 2016.

[3] Dechezleprêtre et al., 2013.

[4] Dechezleprêtre et al., 2016, p.15.

Looking forward, heavy reliance on forest sinks to claim a net zero emissions target in some future year risks masking the reality that gross emissions of fossil carbon dioxide could easily remain stubbornly high under the current approach. Modelling for the Productivity Commission suggested that even if New Zealand met a target of net zero emissions by 2050, gross emissions would still only be roughly 40 per cent below their 2015 level.

A key question for policymakers then is the extent to which they want to construct emissions reduction targets and climate policies around an accounting outcome, or want to clearly signal and incentivise a real and enduring transition to a truly low-emissions economy.

New Zealand's current approach to forestry accounting

New Zealand's approach to forestry accounting for the NZ ETS is closely aligned with international accounting rules. As with the Kyoto Protocol, a distinction is made between pre-1990 and post-1989 forests.

From a physical science point of view there is nothing special about the year 1990, and this arbitrary categorisation has led to perverse outcomes in some cases. For example in the NZ ETS, a block of land set aside for grazing in 1992 that now contains regenerating scrub or forest may be cleared without any liability for carbon loss to the landowner (assuming it was not registered for carbon credits in the NZ ETS, which is a voluntary activity). Conversely, a neighbouring block of land set aside to regenerate into native forest just three years earlier would automatically require a carbon payment if cleared for pasture because it falls on the other side of the Kyoto-based 1990 cut off.

The rules for counting carbon storage on forest land in the NZ ETS are based on UNFCCC guidelines. Tree species must be capable of reaching a minimum of 2–5 metres, land must have a canopy cover of 10–30 per cent, and the area should be a minimum of 0.05–1 hectare.

New Zealand opted for the high end of each range, so forest land is currently any land greater than one hectare on which the tree species reach a height of at least five metres and with greater than 30 per cent canopy cover.[5] There is also an additional rule that the forest should have a minimum width of 30 metres. There have been calls for these rules to expand to allow the inclusion of more trees.

How forests are counted in the NZ ETS is currently under review, and Cabinet has recently approved a number of changes.[6] Some of the changes being made are to better align the NZ ETS with how New Zealand intends to account for forests under its commitments to the Paris Agreement after 2021.[7] These new rules, which will supersede Kyoto, are close to being finalised.

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[5] This includes land that has the potential to reach these criteria.

[6] Jones, 2018.

[7] "This change to international settings will mean from 2021 onwards, New Zealand's ETS forestry accounting approach will not align with how New Zealand forestry emissions are recognised internationally." (Ministry for Primary Industries, 2018, p.21)

Another related international forestry accounting debate is whether to recognise the carbon stored in harvested wood products (HWPs). Fully recognising HWPs in forestry accounting would provide foresters in New Zealand with more revenue, help incentivise more tree planting and encourage investment in wood processing.[8]

However, the NZ ETS does not currently account for HWPs, but rather assumes instant release of carbon from forest products on harvest. This makes foresters liable for an emission that has not occurred yet.

The international accounting rules used for New Zealand's Nationally Determined Contribution (NDC) under the Paris Agreement should allow HWPs to be accounted for. There is not yet agreement, however, on how this should be done.[9]

Testing an alternative approach for New Zealand

The alternative approach outlined in chapter four would treat fossil and biological emissions separately. Furthermore, only biological emitters would be able to mitigate the warming impact of their emissions using forest sinks. This would have implications for both targets and policies.

The separation of fossil and biological emissions implies separate targets for the two 'bundles'. This is to provide transparency about the different challenges the different gases pose. For fossil emissions, the long-term target has to be zero if New Zealand's contribution to warming is to be stabilised or reduced. If there are residual emissions they would need to be compensated for by negative emissions technologies.

For the biological gases, a target below current levels is needed if the contribution to warming from this source is to be stabilised or reduced, but this need not necessarily be zero because these gases do not accumulate in the atmosphere to the same extent as carbon dioxide.

The question is more about the amount of ongoing warming New Zealand is prepared to argue is an acceptable by-product of agricultural production. This is not a matter international negotiations have pronounced on, but as one of the most efficient agricultural producers, any target for biological gases New Zealand adopted would be the subject of significant interest.

Policies to set about achieving the targets would also need to be separated. For fossil carbon dioxide and fossil methane, it would make sense to continue to address them through the NZ ETS. The NZ ETS already exists with nearly all fossil emitters registered to the trading scheme. Starting again with an alternative climate policy instrument would be costly in every sense.

But for biological sources and sinks, a separate set of policies would need to be constructed. Box 5.1 expands on potential policy instruments that could be used to manage biological gases and forest sinks under the alternative approach.

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[8] Forestry Reference Group, 2018.

[9] There are two main competing accounting approaches – the stock change or consumption-based approach and the production-based approach. New Zealand favours the latter option, which follows the fate of a log wherever it goes. Ultimately, a consensus is needed between all countries to use a single method.

Box 5.1. Policies to manage biological sources and sinks under the alternative approach

At a high level, potential policy instruments to reduce biological emissions and allow offsetting through forest sinks can be either regulatory or price-based (or some combination of both).

Well-designed emissions pricing is likely to have lower abatement costs, as it provides emitters with an ongoing incentive to seek out low-cost abatement opportunities. The flexibility it provides could also be expected to encourage more innovation than a regulatory approach.

While emissions pricing is likely to have lower abatement costs, regulations could possibly deliver lower transaction costs. This conclusion is supported by the recent Biological Emissions Reference Group (BERG) report, which reviewed the annual administrative costs of these policy instruments.[10]

The level of the target's ambition is likely to be decisive in choosing between pricing or regulating for a reduction in biological emissions. If the ambition level is low, then transaction costs would dominate, and a regulatory approach would be more cost-effective. If the ambition level is higher, then abatement costs would start to dominate, and a pricing approach would be more cost-effective.[11]

Given New Zealand's commitment to the Paris Agreement, the level of biological emissions reduction being targeted is likely to be sufficiently ambitious to favour emissions pricing. Although these emissions do not need to be reduced necessarily to zero, gross reductions in biological methane have been discussed in the order of at the very least ten per cent by 2050 from 2016 levels.[12]

As to the type of pricing instrument that might be adopted, it has been noted that the "instrument through which this signal is provided – [emissions trading scheme], emissions tax or a hybrid of the two – is of secondary importance."[13] However, the simplicity of a tax/levy suggests that a levy might be preferable. Research also suggests that monitoring, reporting and verification costs are lower for a levy.[14]

The often discussed downside of a levy is that it provides less certainty that a target will be met. However, the levy rate can be adjusted periodically with emissions budgets to reflect the speed of progress being made towards the target. By linking adjustment of the rate to each new emissions budget, a rising levy rate could be institutionally embedded in a way that provided as much confidence as a trading

[10] Biological Emissions Reference Group, 2018.

[11] Joas and Flachsland, 2016.

[12] The Parliamentary Commissioner for the Environment (2018) reported that emissions would need to be reduced by at least 10–22% below 2016 levels by 2050, and 20–27% by 2100, to ensure biological methane from agriculture contributes no additional warming beyond the current level. Further, the IPCC found that reductions of 35% or more in global methane emissions by 2050 from 2010 levels would be consistent with limiting warming to 1.5 °C (Intergovernmental Panel on Climate Change, 2018a).

[13] Leining, 2017, p.9.

[14] Coria and Jaraite, 2018.

institutionally embedded in a way that provided as much confidence as a trading scheme can of meeting a given target. It also has to be remembered that for trading schemes to deliver targets, policymakers have to be prepared to tolerate a constant tightening of the cap. This is not necessarily any easier politically than raising the levy rate.

In the case of a levy, the revenues would be recycled to support carbon sequestration through forestry.[15] Some revenues, whether from a trading scheme or taxation could also be used for research and development to accelerate innovation designed to lower the costs of abatement.

The BERG report highlighted that if research and development were carried out to successfully commercialise new abatement technologies, then gross biological emissions could potentially be reduced between 22 and 48 per cent in 2050. Appendix one indicates a set of proposed abatement technologies to reduce biological methane and nitrous oxide, including the trade-offs and synergies between them.

The removal of forestry as an offsetting mechanism in the NZ ETS and forbidding its use to offset fossil emissions would make it easier to link the NZ ETS to trading schemes in other countries, should New Zealand wish to do so in the future.

The NZ ETS is currently the only emissions trading scheme in the world to fully cover both emissions and removals from the forestry sector. The removal of forestry would also avoid the potentially undesirable outcome of New Zealand becoming a large-scale carbon sink for the world if relatively cheap units were sold abroad.

To meaningfully offset fossil carbon dioxide emissions, sequestered carbon needs to remain safely stored in terrestrial pools in perpetuity. The permanence of forest sinks cannot be guaranteed. However, negative emissions technologies (e.g. BECCS), unlike forests, could provide a near-permanent removal of carbon dioxide from the atmosphere. While negative emissions technologies have not yet been commercialised at scale, auctioned revenues from the NZ ETS could be hypothecated to support their development.

If the absence of forest offsets was judged to expose some fossil emitters to unacceptably high abatement costs (e.g. aviation), access to international units could be an alternative way of providing some relief. The potential for limited provision of international units for fossil sectors with high abatement costs could alleviate some competitiveness concerns without the long-term need for free allocations, which could be phased out over time.[16] Access to international units should only be for units of high environmental integrity that have shown demonstrable gross fossil emissions reductions.

[15] A biological emissions tax could apply to biological carbon dioxide emissions from land use change, in addition to emissions of biological methane and nitrous oxide. This would provide an incentive not to convert existing forest land into other land use types.

[16] Dellink et al., 2014.

Modelling the climate policy approaches

To understand how the alternative approach might differ from the current approach, Motu Economic and Public Policy Research (Motu) and Concept Consulting were commissioned to undertake some modelling work. High-level detail of the models applied and the key modelling assumptions behind them are described in appendix two as are the modelling assumptions used to describe how key factors change over time, including the rates and types of technological change.

Importantly, the assumptions regarding technological change were conservative ones. For example, the modelling assumed that there would be no technological breakthrough (e.g. a methane vaccine) discovered for reducing biological emissions, but there would be an ongoing improvement in the efficiency of emissions per unit of agricultural product produced in line with historical trends.

Motu and Concept Consulting applied the same models that were used to provide insights in last year's *Low Emissions Economy* report by the Productivity Commission.[17] As a result, there is an underlying consistency in the modelling approaches. But the modelling applied here also had a number of differences. Where the Productivity Commission investigated only the current approach against different background scenarios and targets, this exercise sought to contrast the current approach with an alternative approach that separates fossil emissions from biological sources and sinks.

It was also decided to investigate a time horizon out to 2075, rather than 2050. While 2050 has been the subject of political commitments, there is no magic about the year 2050. At the international level, the Paris Agreement simply indicates the need to balance sources and sinks in the second half of this century. For this reason, 2075 was considered to be an appropriate long-term target year for modelling purposes. New Zealand needs to be well down the track to meeting the Paris Agreement's goal by 2050. But insisting on a position of net zero emissions in that year could entail any number of different contributions from sources and sinks.

In a world where all sources and sinks are fully substitutable, this would not be a concern. But by modelling out to 2075, it becomes possible to understand the impacts of forest offsetting over the long term. As the Productivity Commission itself noted, "the heavy reliance on forestry could create longer-term challenges – with continued emissions reductions required after 2050 to maintain net-zero emissions."[18] Or, as they might have added, continued new forest planting to offset ongoing emissions.

To provide a basis for comparison, the current approach was modelled as follows:

- all New Zealand emissions were modelled under a single emissions price
- forest sinks were available to offset all emissions
- up to ten per cent of all emissions could be mitigated through the purchase of international units.

[17] Productivity Commission, 2018.

[18] Productivity Commission, 2018.

Given the current interest in a target of net zero emissions by 2050, this was also adopted with the proviso that this outcome should be maintained through to 2075.

By contrast, the alternative approach of separating biological sources and sinks was modelled as follows:

- separate emissions prices for fossil and biological emissions
- no access to forest sinks by fossil emitters, but up to 20 per cent of fossil emissions could be mitigated through the purchase of international units
- a target of zero (gross) fossil emissions by 2075
- forest sinks were available to offset biological emissions
- a target of net biological emissions reductions by 2075 of either 20 per cent or 100 per cent (i.e. net zero biological emissions) below 2016 emissions levels.

The 20 per cent and 100 per cent reduction targets for net biological emissions were chosen as minimum and maximum ambitions for modelling purposes. Policymakers considering the alternative approach should endeavour to undertake further analysis to determine an appropriate level ambition for a biological emissions reduction target. Table 5.1 details and summarises the climate policy approaches modelled against their respective emissions reduction targets.

Table 5.1. Climate policy approaches and emissions reduction targets modelled.

Climate policy approach	Sectors and gases covered	Emissions reduction target in 2075	Sectors where forest offsetting allowed	Level of international units allowed	Price of international units in 2075
Current approach	All sectors, all gases	Zero (net) emissions	Forest offsetting allowed	10%	Rising to $150
Alternative approach	Fossil sector, fossil gases	Zero (gross) emissions	No forest offsetting	20%	Rising to $150
	Land-based sectors, biological gases	20% net reduction	Forest offsetting allowed	0%	-
		100% net reduction (i.e. net zero biological emissions)			

Before discussing the modelling results, it is important to note that any use of modelling has to come with the proviso that models are vastly simplified representations of reality. In this case, the models only focus on key factors of production and relationships between and within critical emitting sectors. They are unable to tell us anything about the long-term damages from climate change or any potential benefits from implementing emissions reduction targets and associated climate policies. Furthermore, there are limitations to the modelling. For instance, biological methane emissions from the waste sector were modelled under a fossil emissions price.

While modelling can provide useful insights, these insights are only illustrative and can provide no more than a 'feel' for what the current and alternative approaches might yield. Modelling does not provide categorical predictions of the future.

What the modelling can tell us is that different treatments of the different sources and sinks will yield very different environmental, economic and land use outcomes. Policymakers need to be prepared to test different approaches rather than accept without argument that there is no alternative. There are always alternatives.

Impact on gross emissions

The modelling results indicate some notable differences in emissions reductions between the two approaches, irrespective of the different targets required to be met by each approach. Figure 5.2 shows that for gross fossil emissions, the current approach yielded an 85 per cent reduction below 2018 levels, leaving six megatonnes of carbon dioxide emitted in 2075. On the other hand, the alternative approach yielded larger reductions, with an 89 per cent reduction in gross fossil emissions leaving only 4.3 megatonnes of carbon dioxide in 2075.[19]

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[19] Gross fossil emissions (2019-2075) for the two climate policy approaches.

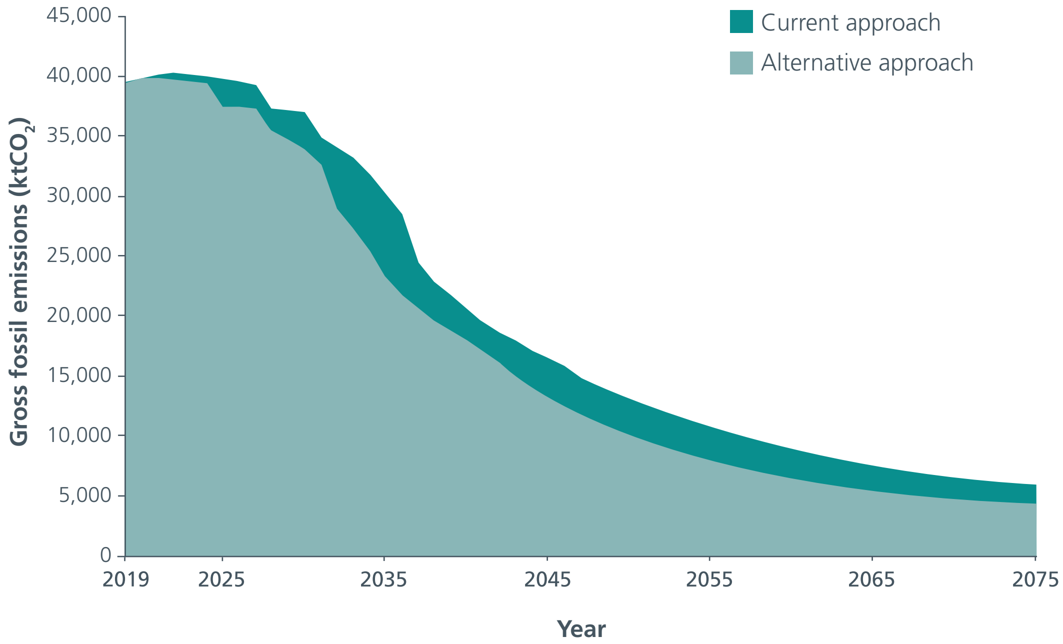

Figure 5.2. Gross fossil emissions (2019-2075) for the two climate policy approaches.

Figure 5.3 shows that for gross biological emissions from agriculture and waste, the reverse effect occurs, albeit more gradually. The current approach yielded a higher reduction in biological emissions compared to the alternative approach, with a 28 per cent reduction below 2018 levels leaving 29.2 megatonnes of carbon dioxide equivalent emitted in 2075.

The alternative approach, requiring net zero biological emissions in 2075, yielded a reduction of 24 per cent. Interestingly, the less ambitious target of requiring only a 20 per cent reduction in net biological emissions still yielded a sizeable gross biological emissions reduction of 21 per cent.

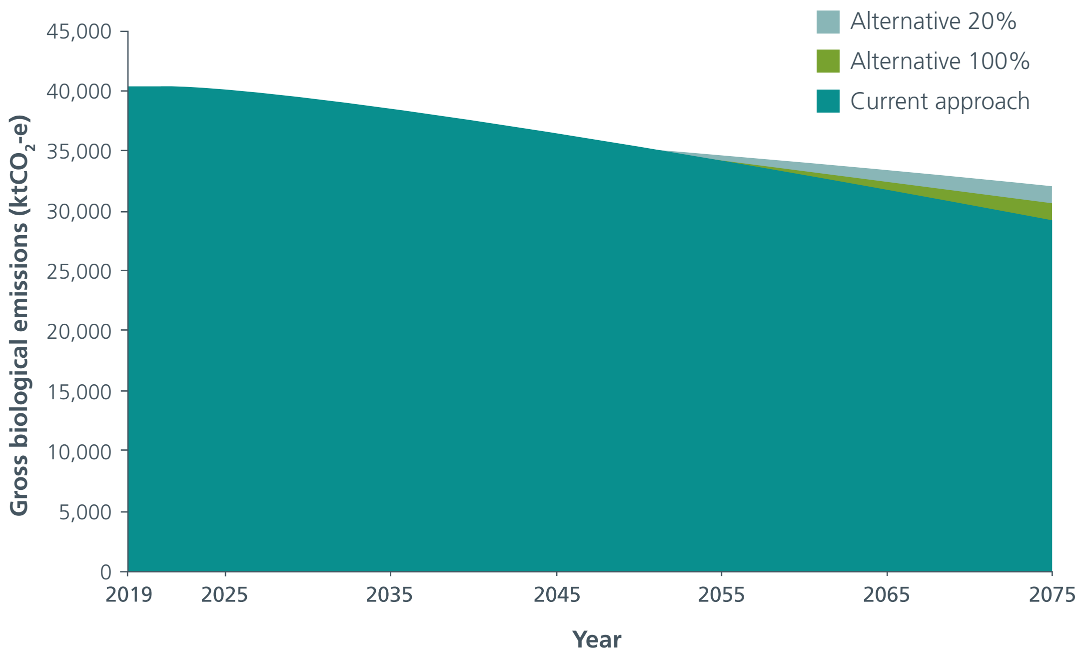

Figure 5.3. Gross biological emissions from agriculture and waste (2019-2075) for the two climate policy approaches.[20]

The reduction in gross biological emissions, even with a less ambitious target, suggests that some cheap abatement opportunities exist for reducing gross biological emissions and that forest offsetting occurs once these abatement opportunities are no longer available.

This finding is in line with recent modelling conducted by BERG indicated that a 10 per cent reduction in biological emissions could be achieved using currently available abatement opportunities.[21] That report also noted that higher reductions in gross biological emissions would likely require some land use change to forestry.[22]

Despite the differences in gross reductions in biological and fossil emissions between the approaches, overall gross emissions reductions were very similar. Modelling results indicated that the current approach would see gross emissions reduced by 44.3 megatonnes of carbon dioxide equivalent below 2018 levels in 2075. Under the alternative approach the reduction would be between 43 and 44.5 megatonnes of carbon dioxide equivalent, depending on the ambition of the target level.

The modelling exercise did not require New Zealand's first NDC under the Paris Agreement of a 30 per cent reduction below 2005 gross emissions levels to be met. However, the model's findings provide an insight into whether that target will be

[20] Biological emissions from waste were modelled under a fossil emissions price, but were separately added to biological emissions from agriculture in figure 5.2. Note that biological emissions from agriculture resulted in a 26% reduction below 2018 levels for the current approach, and the alternative approach with a 100% biological emissions reduction target resulted in 20% reduction.

[21] Biological Emissions Reference Group, 2018.

[22] A better definition of abatement technologies and management practices to improve modelled sensitivity of land use change to emissions prices should be the subject of future modelling development.

achieved in the process of reaching longer-term targets in either 2050 or 2075. The result is not encouraging. A shortfall of between 15.3 and 18.7 megatonnes of carbon dioxide equivalents is indicated for the alternative approach and current approach, respectively.

Impact on emissions prices

Not surprisingly, to achieve these significant reductions in emissions over the long term, emissions prices were modelled to rise strongly over the transition period to reach the emissions reduction targets.

For the current approach, emissions prices were modelled to increase from around $25 per tonne of carbon dioxide equivalent today to up to $203 by 2075. Under the alternative approach where fossil emissions did not have access to forest offsets, emissions prices rose to $350 per tonne of carbon dioxide by 2075. Figure 5.4 shows the emissions price paths for both climate policy approaches.

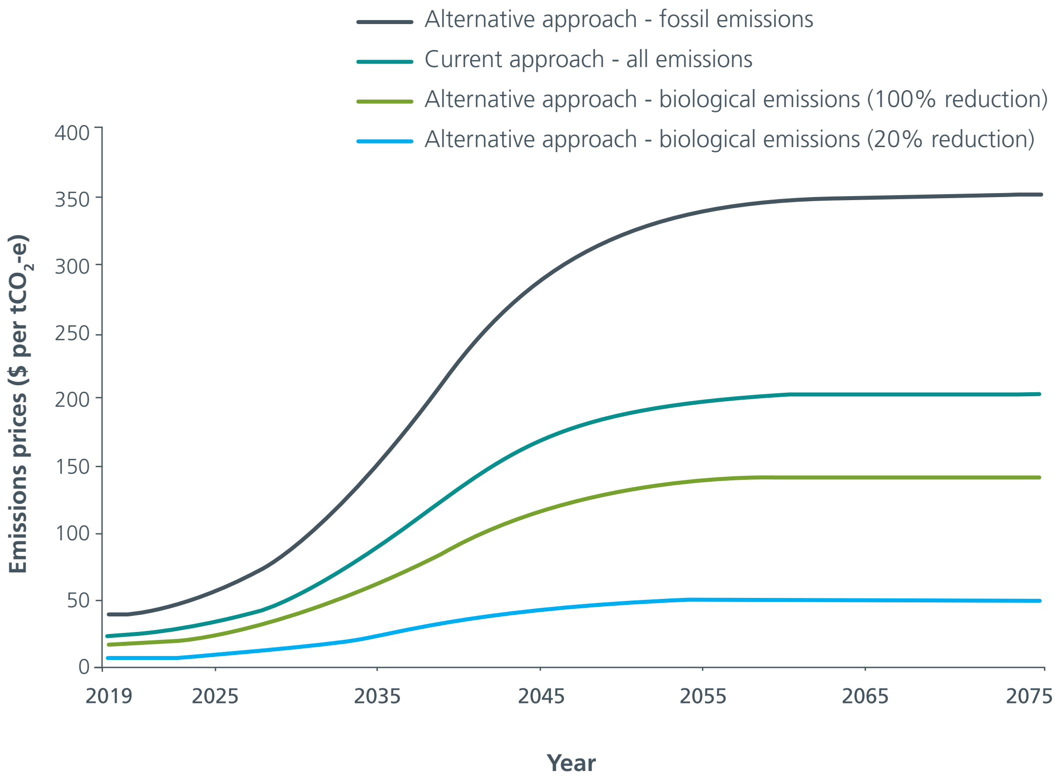

Figure 5.4. Emissions price paths (2019-2075) for the two climate policy approaches.[23]

The modelling results indicate a higher emissions price for fossil sectors under the alternative approach than the current approach, but a lower emissions price for the land-based sectors for biological emissions of between $48 and $141 per tonne of carbon

[23] 'Fossil emissions' reflects the fossil emissions price path under the alternative approach. While 'biological emissions' reflects the biological emissions price path under the alternative approach, and depends on the target level to be reached.

dioxide equivalent by 2075. As expected, the lower the net target for the alternative approach, the lower the biological emissions price required to reach the target.

While not shown in figure 5.3, modelling analysis was also performed for the current approach without international units. That analysis observed, as expected, a higher emissions price (i.e. $237 per tonne of carbon dioxide equivalent by 2075) than with international units being available.

Impact on New Zealand landscapes

The extent to which New Zealand relies on forest sinks to soak up its fossil carbon dioxide emissions will have a profound effect on the landscape and many rural communities. The modelling results illustrate this.

For the purposes of the modelling exercise it was decided that new forest planting would be in the ratio of one third continuous cover native reforestation to two thirds plantation forests of radiata pine. This was a specific assumption made in the model, although one that is not unreasonable for two reasons.

First, if benefits other than just carbon sequestration are being pursued (e.g. biodiversity conservation or soil erosion mitigation), radiata pine plantation forests may not always recommend themselves. Secondly, if the rapid sequestration and cycling of carbon in radiata pine plantations occurs in broadly the same time frame as the warming from methane, a share of native reforestation[24] would provide sequestration over the sort of time frame that nitrous oxide exerts its warming influence.

With the current approach, the modelling found that the area of Aotearoa New Zealand under forest cover is projected to increase from today's levels by an additional 2.6 million hectares by 2050 to reach a net zero emissions target, and a further 2.8 million hectares to maintain that target by 2075.

The alternative approach that restricted forest offsets to biological emitters would see 3.9 million hectares of additional forest by 2075 under a net zero biological emissions target, or 1.6 million hectares if the target were a 20 per cent reduction in net biological emissions.

The difference in additional forested area between the two approaches is notable. Under the least ambitious target using the alternative approach, sheep and beef farming remains the dominant land use, although markedly reduced. Under all the other modelled options forestry dominates. The potential for change is so profound that New Zealand would be well advised to understand the full consequences to the environment and the economy, in addition to what it would represent in terms of greenhouse gas accounting.

Figure 5.5 illustrates the difference in the growth of forestry over time under the two climate policy approaches, as well as the contraction in the sheep and beef farming sector and scrubland as a result of the reforestation.

[24] 'Reforestation' is used here to describe the creation of any new forest in New Zealand. The term is used in preference to 'afforestation' in this context, to reflect the fact that land was largely covered in forests prior to the arrival of humans.

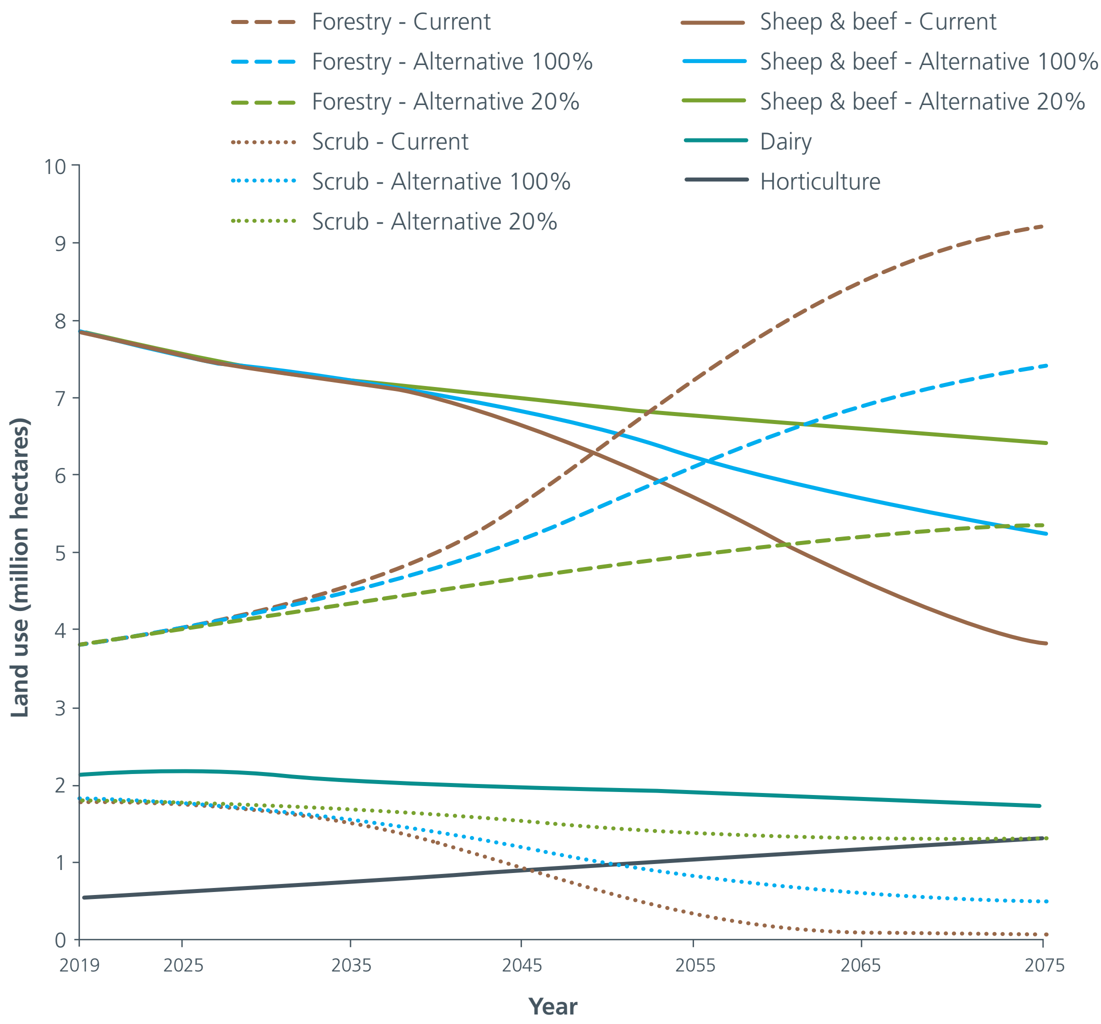

Figure 5.5. Modelled land use over time with the implementation of the two climate policy approaches.[25]

The biggest change under either climate policy approach is the shift from sheep and beef farming to forestry. The reduction in emissions is small and incremental. This is largely because land use change from sheep and beef farming to forestry is projected to occur at even relatively low emissions prices, but also because some of the first land to convert will be marginal country that already has a low emissions profile.

Figure 5.5 also indicates the changes in land area under dairying and horticulture. The results indicate an increase in horticulture and a decrease in dairying. The expansion of horticulture is primarily at the expense of dairying. So the model projects what might be expected, in that dairy and horticulture are largely substitute land uses, as are sheep and beef farming with forestry.

[25] Scrubland reflects land not used for productive purposes.

The observed changes in dairying and horticulture are small in comparison with those affecting sheep and beef farming and forestry. This is, in part, an artefact of the modelling. The land area in horticulture was assumed rather than generated by the model.[26] It was assumed that horticulture would expand to 1 million hectares across the country by 2050 and continue to grow on a linear path until 2075. In the case of dairying, the model has limited price sensitivity.[27]

Interestingly, the projected land use changes under the current approach are likely to broadly align with an approach proposed by the Productivity Commission, which bears resemblance to the current approach described in box 5.2.

Box 5.2. How the alternative approach compares with the approach proposed by the Productivity Commission

The Productivity Commission proposed a variation of the current approach where nitrous oxide would be treated as a 'long-lived' gas and enter the NZ ETS with fossil carbon dioxide and forestry. The target for these sources and sinks would be 'net zero long-lived gases' by 2050.

Methane as a 'short-lived' gas was proposed to be managed under an alternative policy instrument, such as a methane quota system. It was not required to reach zero, but rather its gross level of emissions was to be stabilised. This approach recognises the relatively short-lived warming effect of methane, but does not account for the risks of impermanence that are posed by forest offsets of fossil carbon dioxide.

The long-lived/short-lived variation would be expected to result in a smaller area of forest planting compared to the current approach, given that gross methane emissions would not be offset. However, it would be expected to stimulate considerably more new forest plantings than the alternative approach. This variation could also have higher transaction costs than the alternative approach, as some biological emitters might be required to engage with two separate policy instruments (e.g. NZ ETS for nitrous oxide emissions and a quota system for methane emissions).

[26] Horticulture land use responds only exogenously in the modelling, rather than endogenously like other productive land uses as the data available for this sector remains limited. However, the modelling does spatially allocate horticulture to suitable land based on geophysical and other characteristics of the land.

[27] The limited responsiveness of the dairy sector is largely driven by two interrelated factors. The first is that if dairy were unconstrained in the model, land area in dairy would tend to increase, even with a rising emissions price, because the cross-emissions price impact between sheep and beef farming and dairying dwarfs the estimated own-emissions price impact on the dairy sector.

This potential increase in dairying with a rising emissions price, however, is limited because dairying expansion is constrained beyond 2025 due to a second factor, which is the assumed implementation of freshwater quality regulations across New Zealand's catchments. Depending on how they are implemented, freshwater quality regulations could reduce biological emissions from farms.

There are a range of mitigation options that have been identified that can help reach stricter nitrogen targets in freshwater environments, and many of these will also reduce nitrous oxide emissions. These include reducing nitrogen fertiliser application rates, restricting grazing of pasture or crops at certain times of the year, the use of barns for wintering, improved effluent management and reducing stocking rates. Some of these actions will also affect methane emissions, but not always.

Finally, the limited conversion of dairy land into forestry projected in the modelling may also make economic sense in that such a change could result in a significant loss in land value. Given this potential loss, such conversions might be readily resisted. Hence, the limited price sensitivity of dairy, despite a rising emissions price, might be expected.

Under both approaches, the distributional impact of reforestation is skewed towards three regions in particular. Figure 5.6 illustrates that reforestation is projected to be concentrated in Canterbury, Otago and Manawatū-Whanganui under the current approach. Canterbury, in particular, is projected to see plantation forestry increase by as much 862 per cent in 2075 from current forest levels.

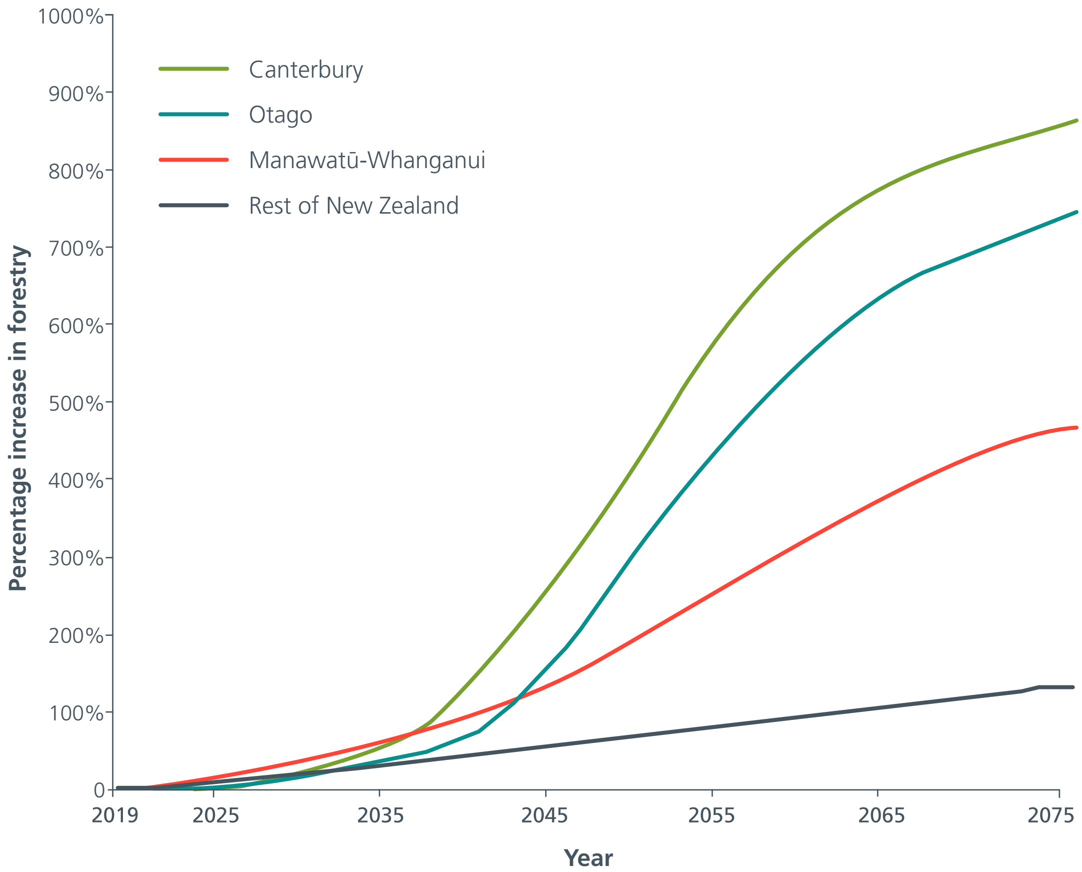

Figure 5.6. Percentage increase in forestry by region under the current approach.

While not shown in figure 5.6, the same regional distributional impact is projected to occur under the alternative approach. However, the increase in forestry is projected to be much lower at a 201 per cent or a 596 per cent increase in Canterbury, depending on the ambition of the target for net biological emissions.

Coping with the transition

The modelling results provide a highly schematised picture of how events might evolve under the two different approaches. Governments have to deal with real businesses and communities that cannot adapt overnight, and consumers who will ultimately wear the inevitable costs that flow through into the cost of living.

In the same way that the expected temperature impacts of targets should be able to be transparently described, credible transition pathways that are economically and socially sustainable need to be able to be debated. In the future, the proposed Climate Commission will have to offer these assessments as it elaborates a succession of emissions budgets designed to keep the economy on course to meet whatever emissions reduction targets are legislated for.

The following sections seek to provide some insights into the sustainability of prices for fossil and biological emissions and land use changes that might be faced in the alternative approach. Importantly, some of the policy implications developed could also be applied to the current approach.

How will New Zealand manage to adapt to rising fossil emissions prices?

Prices for fossil emissions of up to $350 per tonne of carbon dioxide inevitably raise questions about their economic and political sustainability.[28] A number of points need to be considered.

In the first place, an emissions price of $350 per tonne of carbon dioxide is a modelled price in 2075, over half a century from now. The real issue is how rapidly that price evolves from its current level of around $25. It needs to rise consistently to send an unequivocal signal that fossil emissions will never be cheaper. That does not require a massive increase overnight, but rather a steady emissions price path that businesses and consumers can plan in advance to absorb as they come to replace equipment, appliances and vehicles.

It needs to be stressed that an emissions price of $350 per tonne of carbon dioxide by 2075 is the product of a modelling exercise that is based on conservative assumptions about technological change, and a very imperfect understanding of how fast the cost of new technologies will fall and what completely new abatement technologies will emerge over the long term. What actually happens in the real world will almost certainly rewrite the sorts of prices that will be needed to nudge New Zealanders away from fossil fuel.

This is because steadily rising prices would be expected to drive innovation on many fronts. Many opportunities to switch away from fossil fuel consumption will present themselves long before prices reach anything like $350 per tonne of carbon dioxide. It is simply a modelled price level based on current knowledge that will soon be out of date as new technological advances currently on the horizon start to be deployed commercially.

That said, the modelling results are not out of step with the sort of emissions prices likely to be necessary in the rest of the developed world if the goal of the Paris

[28] A sense of what an emissions price of $350 per tonne of carbon dioxide would be can be gained from this, admittedly simplistic, conversion: a litre of petrol produces 2.3 kilograms of carbon dioxide. This means the price of a litre of petrol at the pump could increase by about 23 cents for every $100 per tonne of carbon dioxide, which means that an emissions price of $350 would raise petrol prices by around 80 cents per litre from today.

Agreement is to be met.[29] Equally, it would be fair to say that any 'comfort' that can be gained from this depends on widespread international determination to take the necessary measures to make it possible.

Interestingly, the modelling results indicate that for many sectors, emissions prices may play only a relatively minor role as gross reductions in fossil emissions are modelled to occur irrespective of the existence of an emissions price. To test the sensitivity of emissions reductions to carbon prices, an emissions price falling to just $1 per tonne of carbon dioxide equivalent through to 2075 was modelled. The result is depicted in figure 5.7.

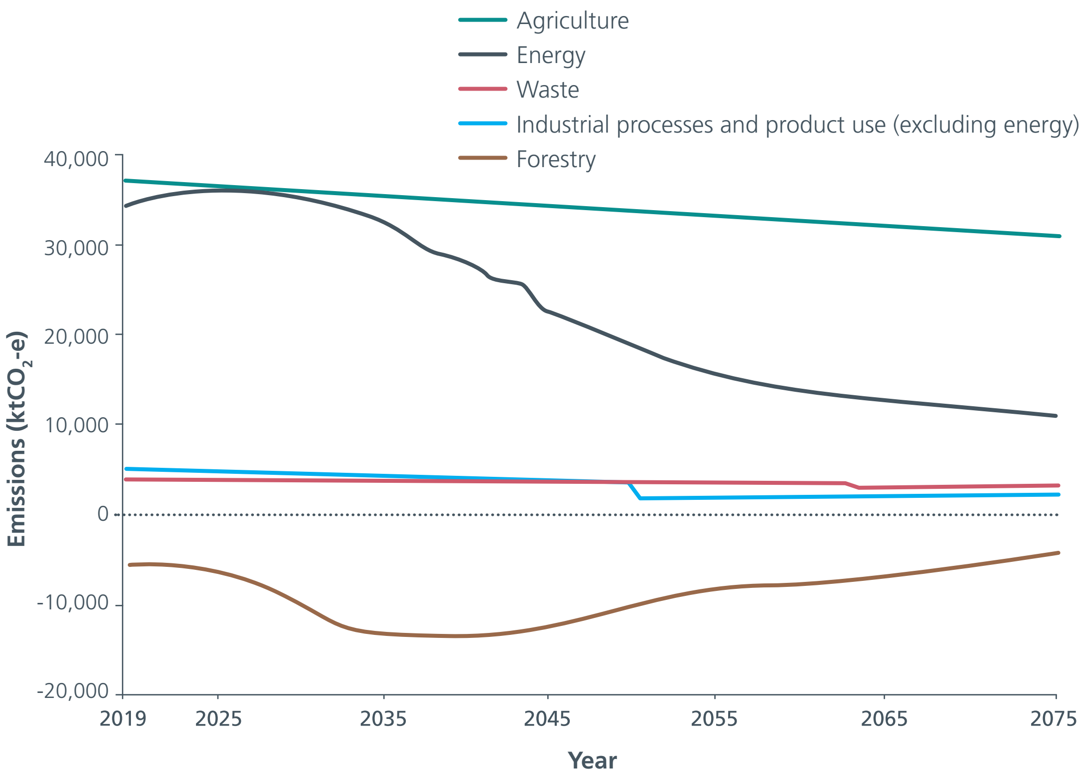

Figure 5.7. Projected sectoral gross emissions where emissions prices fall from current levels to $1 per tonne of carbon dioxide equivalent by 2075.

The model predicts large reductions in energy emissions while other sectors remain largely unchanged. This outcome in the absence of significant emissions pricing can be attributed to the sustained momentum of technological change that is underway in power generation and parts of the transport sector.

The modelled emissions reductions from power generation are particularly striking due to projected improvements in solar, wind and battery technologies. For example,

[29] Scenarios that limit warming to below 2 °C with a greater than 66% probability imply emissions prices increasing throughout this century, with prices in 2050 ranging from US$45 to US$1000 (in 2005 US dollars) per tonne of carbon dioxide equivalent if the world moved gradually, but permanently towards a more sustainable path (Carbon Pricing Leadership Coalition, 2017).

modelling results indicate that wind generators will eventually replace baseload gas-fired generators, irrespective of a price on fossil emissions. Similarly, the deployment of wind power is projected to grow by well over 900 per cent by 2075 from current levels regardless of an emissions price being imposed.

Likewise in the transport sector, electric vehicles are expected to become significantly cheaper than internal combustion engine vehicles through improvements in battery technology irrespective of an emissions price. The modelling indicates that electric vehicle uptake will be rapid and see over 70 per cent of the light vehicle fleet in New Zealand being electric by 2050, and over 95 per cent by 2075 under either climate policy approach. Again, this is modelled to occur irrespective of an emissions price.

Care should be taken not to interpret these results as an argument for doing nothing on the basis that technology and business innovation will resolve the problem. Emissions in 2075 at the level shown in figure 5.7 are still far too high. If that is the best New Zealand and other countries can do, it will be a case of 'game over' in terms of mitigating emissions to avoid temperatures rising above two degrees Celsius.

New Zealand needs to be much closer to gross zero fossil emissions by then. Figure 5.7 illustrates that there are enough technological pathways to give us reasons to expect that strong emissions pricing will bring those innovations forward. But it also draws our attention to the 'hard' residual emissions. The IPPU sector (i.e. industrial processes and product use) barely budges.[30] This embraces a raft of very emissions-intensive and trade-exposed (EITE) industries for which easy technological fixes are not readily available.

Low cost abatement technologies for industries such as steel and cement are unlikely to be found swiftly or originate from a branch line economy like New Zealand. Similarly, the remaining energy emissions include hard cases such as aviation, for which no technological fix currently exists.

For these difficult cases, strong emissions prices can promote improvements at the margin. But in the absence of technology pathways to negative emissions technologies, rising prices could soon compromise the competitiveness of some of these sectors. Rather than delay a credible and rising economy-wide fossil emissions price, a number of pragmatic sectoral solutions could be explored, including the maintenance of free allocation for these EITE industries and access to international units (if indeed these can be found).[31]

The purpose of any of these policy 'fixes' should be explicitly acknowledged as buying time and not be regarded as a permanent solution. As such they would need to be under regular review.

[30] The IPPU sector includes the cement, steel, aluminum, methanol, urea, lime and refrigeration industries.

[31] It is recognised that cheap international units will be limited if all countries make substantive reductions to their gross emissions through to 2075.

A way of hastening needed technological innovation, especially for EITE industries could be to allocate some of the auction revenues from the NZ ETS to research and development of low cost abatement technologies in these industries (or other supporting negative emissions technologies). This financial support, however, needs to be considered in the context that many of these breakthrough technological solutions will be developed abroad.

Figure 5.7 also shows emissions from the land-based sectors declining very slowly in the absence of an emissions price. Unlike fossil emissions, biological emissions from agriculture are not expected to reduce significantly in the absence of an emissions price.

This is in part a reflection of the fact that few abatement technologies for biological emissions are available that can be plausibly modelled. It should not be interpreted to mean there are no ways to make progress. New Zealand is working on a wide range of strategies targeting animals, forage and fertilisers that could yield significant improvements in emissions intensity. An emissions price could be expected to incentivise the deployment of these innovations.

What the model can tell us is that forest offsets are likely to be able to deliver significant net biological emissions reductions, as forestry is projected to be very sensitive to an emissions price. That raises the other big question New Zealand faces in addition to sustainable emissions prices: how much land use change is New Zealand prepared to contemplate for the sole reason of reaching an emissions reduction target?

How fast could a biological emissions price be introduced?

The emissions prices being faced by biological emitters in the alternative approach are significantly lower than those facing fossil emitters. It might on the face of it appear that biological emitters would be receiving favourable treatment. But that would be to ignore the different risks the different gases pose. Neither would biological emitters be relieved of their deep reliance on the fossil economy. Farming and forestry alike are presently dependent on fossil fuel for the processing of raw materials and the business of moving both commodities and finished products to market.

The limited abatement technologies available for biological methane and nitrous oxide highlight the importance of a slower transition for incentivising the reduction of biological emissions from agriculture than for fossil emissions. A steady transition would allow time to focus on developing the institutions and policy instruments needed to generate a biological emissions price, as well as managing the phase-out of access by fossil emitters to forest offsets through the NZ ETS. Providing biological emitters from agriculture with a measure of free allocation (or relief that mirrors free allocation) would help avoid the disruption that immediate exposure to the full emissions price could cause, such as sudden changes to land prices and loss of competitiveness in overseas markets.

Most farms in New Zealand are occupied and run by the landowner, so the distributional impact of biological emissions pricing could be significant in rural communities. If biological emissions prices were too high early in the transition, biological emitters could face potentially abrupt losses in land values, especially given the limited availability of abatement technologies and the fact that land use change cannot happen overnight.[32]

Preliminary economic analysis undertaken in the Taupō and Rotorua lake catchments has found that nitrogen leaching restrictions and nitrogen pricing have resulted in land prices being discounted by 27 per cent for dairy farms and 37 per cent for sheep and beef farms within the catchments. The higher discount for sheep and beef farming reflects the more limited capacity of this land to being able to be converted to a more profitable land use with the introduction of environmental policies.[33]

The potential impact of emissions pricing on land prices remains uncertain. It is possible that higher emissions prices will lead to higher land prices. If this is so, then there may be no economic advantage in changing land use to forestry.[34]

In the modelling it was assumed that the provision of free allocated emissions units to EITE sectors was consistent with the current NZ ETS settings for both climate policy approaches. Free allocation was initially set at 95 per cent for biological emissions from agriculture. In all cases, free allocation diminished over time before being phased out.

Table 5.2 indicates the emissions prices in 2030 with and without free allocation for the two approaches. It is indicated that emissions prices for farmers with free allocation under the alternative approach would face emissions prices in 2030 that are lower than the current NZ ETS price (~ $25 per tonne of carbon dioxide equivalent).

[32] The Forestry Reference Group (2018; p. 2) highlighted in their recent report that "[t]the potential of the [NZ] ETS to encourage afforestation is confounded by […] the reluctance of farmers to change land use, uncertainty around carbon prices, high land prices, and controls on forest establishment and harvesting. Unless these factors are addressed in ways that fairly spread the sectoral costs it is unlikely we will plant anything like the area of trees suggested in zero-carbon models."

[33] Journeaux (2015) reports on analysis undertaken by Telfer Young of land sales in the Lake Taupō and Lake Rotorua catchments. Of importance, this analysis is preliminary and based on very limited data.

[34] Forestry Reference Group, 2018.

Table 5.2. Emissions prices with and without free allocation to EITE industries in 2030.

Climate policy approach	Sectors and gases covered	Emissions reduction target in 2075	2030 emissions price without free allocation	2030 emissions price for EITE industries with free allocation
Current approach	All sectors, all gases	Zero (net) emissions	$50	$30
Alternative approach	Fossil sector, fossil gases	Zero (gross) emissions	$87	$52
	Land-based sectors, biological gases	20% net reduction	$12	$7
		100% net reduction (i.e. net zero biological emissions)	$35	$21

Table 5.2 also indicates that the 2030 emissions prices for biological emitters under the alternative approach without free allocation were modelled to be in the same region as emissions prices under the current approach with free allocation of emissions units. Therefore, the alternative approach even without free allocation is likely to maintain the competitiveness of biological emitters better than the current approach.

A gradual withdrawal of free allocations would sharpen the choice between wholesale land use change, innovation and seeking premiums in the marketplace to compensate for the emissions price. There could in due course be an opportunity to market New Zealand agricultural products as 'climate friendly' since they would be among the first in the world to be able to demonstrate sufficient mitigation for their warming impact.

A steady transition would also allow time to develop efforts to improve on-farm measurement to accurately estimate emissions at the farm level. By undertaking these improvements it will be possible to bring the point of obligation – or where in the agricultural supply chain compliance and reporting is undertaken – to the farm-level, which will help drive innovation for low cost abatement opportunities to reduce biological emissions. Box 5.3 explains the rationale for this in further detail.

Box 5.3. Point of obligation for biological emissions from agriculture

The point of obligation for biological emissions from agriculture needs to be one that enables easy compliance, monitoring and enforcement. In a perfect world this would be at the point where emissions actually occur. However, this may be either impracticable or too costly, or both. Concern for these transaction costs may lead to a search for alternative points of obligation that may be more cost-effective.

Biological emissions from agriculture are produced at the farm level. So it makes sense to propose that the point of obligation be at the level of the farming enterprise. But it would be equally possible to place the obligation beyond the farm gate at those points such as milk plants or meat works where farm outputs are processed. The advantage of moving the obligation point further downstream is that there are far fewer processors than farmers in New Zealand, making measurement, reporting and verification easier.

While it may be easier to move the point of obligation to processors, it also weakens the incentive for farmers to innovate and pursue on-farm abatement technologies, such as selective breeding, nitrogen inhibitors, methane vaccines and altering feed mixes. These could well be some of the most cost-effective ways to reduce emissions.

Furthermore, a point of obligation at the processor level would require the use of standardised emissions factors, which apply average levels of emissions by farm type. It would trade real-world results driven by the people best placed to influence emissions for simplicity. In the process, significant variation on farms across the country would go unnoticed.

On balance, it seems appropriate to focus attention on the farm level as the point of obligation, with efforts to improve on-farm measurement to accurately estimate emissions at the farm level. Indeed, a farm-level point of obligation would also align with compliance obligations for soil and forest carbon.

Finally, the strength of a biological emissions price would depend on the ambition of the target. Because forest offsets would be available to mitigate emissions, gross biological emissions would not need to fall to zero unlike fossil emissions. The balance between gross emissions reductions and reforestation in meeting any target would be determined by the marginal cost of on-farm mitigation versus forest planting.

Whatever the target level for biological emissions, consideration should still be given to whether a discounting factor should be applied to forest offsets to reflect the fact that the warming effect caused by biological emissions is known with greater certainty than the temperature effects and the degree of non-permanence of forest sinks.[35] The discounting of forest offsets would have the economic effect of increasing the

[35] The case for considering a discount for forest offsets applies equally to the current approach.

emissions price, which would in turn incentivise greater reductions in gross biological emissions. This, as well as the appropriate target for reductions in biological emissions, should be investigated in more detail by the Climate Commission.

How would forestry be treated in the transition?

Denying fossil emitters ongoing access to earning emissions units under the NZ ETS through forest offsets would remove a source of demand for the services of foresters. Depending on the speed with which biological emitters were required to mitigate, this would in due course be replaced by a source of revenue from pricing biological emissions that could be applied to incentivise forestry.

Even under the least onerous 20 per cent net reduction target modelled, 1.6 million hectares of new forestry from today's levels was projected by 2075. The 100 per cent target yielded an additional 3.9 million hectares of forestry over the same time period. However, there would be a transitional period during which demand for new forest planting might be subdued by the phase-out of access to forest sinks by fossil emitters.

As with transitioning to a system of pricing biological sources and sinks, this transfer of forestry between instruments would need to be carefully managed. The need for ongoing assistance for some EITE industries could be provided, in part, through some limited access to forest offsets during this transfer process. This would, in turn, assist the transition for a forestry sector looking to land-based industries as its main source of emissions mitigation demand.

Transitional access to forest offsets for some EITE industries would need to be balanced against the risk that an insufficiently strong fossil emissions price will not shift the economy’s path dependency on emissions-intensive technologies. For the forestry sector, a strong fossil emissions price could be expected to increase the demand for timber products over emissions-intensive products such as steel and cement, resulting in permanent gross fossil emissions reductions.[36]

Furthermore, the likely increased demand for timber products would be expected to result in land conversion from agriculture to plantation forestry, thereby also reducing gross biological emissions permanently. Hence, a transition to the alternative approach needs to balance the competitiveness concerns and the potential of emissions leakage of EITE industries against the likely reductions in gross emissions across the fossil and land-based sectors.

Some concluding observations

Removing access to forest sinks for fossil emitters would be prudent recognition that we do not know how to manage the risks of maintaining impermanent sinks over the timescales needed to match the long-term warming associated with fossil carbon dioxide emissions. It would send a strong signal that since fossil carbon dioxide is the

[36] A strong fossil emissions price would also incentivise the material substitution away from fossil fuels and towards biofuels.

main driver of global temperature rise, serious climate action to tackle New Zealand's gross fossil carbon dioxide emissions can be delayed no longer.

However, using forestry to offset biological emissions makes more sense, as forests and farms are part of the fast biological carbon cycle and nitrogen cycle, and the durations of the warming impacts of biological emissions are similar to the durations of the cooling effects of trees.

Such an approach would enable a zero gross fossil emissions reduction target to be set for fossil carbon dioxide sometime in the second half of the century, with clear progress made towards this target by 2050. A different net target would be set for biological methane and nitrous oxide.

The international community has not yet focused on an appropriate level of reduction for biological gases. As an acknowledged leader in both the measurement and management of biological sources and sinks, New Zealand cannot avoid taking a leading role in this debate. In the circumstances, it would be prudent for the Government to seek the advice of the new Climate Commission in determining an appropriate target level for reducing biological emissions.

The two approaches help confront an important policy choice: to what extent should we store carbon as forests in New Zealand landscapes? Unrestricted access to forest offsets risks the extension of forestry over large areas of Aotearoa New Zealand. A more restricted approach, as proposed in the alternative approach, would still see significant reforestation but without blunting the more ambitious price signal needed to drive reductions in gross fossil emissions. Ultimately, there is no avoiding the latter, since halting runaway climate change at any temperature level requires zero fossil emissions. Storing the waste stream represented by fossil emissions in forest sinks is simply a way of buying time.

At the time climate negotiations commenced, that might have been a justifiable approach, although even then scepticism was raised about whether the time being bought would be put to good use. The sceptics have been proved right.

Far from using the intervening years to push for significant decarbonisation of transport and industry, New Zealand has simply increased its gross fossil carbon dioxide emissions by 35 per cent.[37] Furthermore, a net loss of 50,000 hectares of planted forests occurred between the passage of the Climate Change Response Act in 2002 and the end of the first commitment period of the Kyoto Protocol in 2012.[38] Can we be so sure that 'this time it's different'?

A separation of New Zealand's policy response to fossil and biological emissions would make the desired climate objectives in respect of each of them more transparent. It would also mean that costs would fall differently on emitting sectors with different incentive effects. As we have seen, the removal of forestry from the NZ ETS would

[37] Calculated from New Zealand's interactive emissions tracker (https://emissionstracker.mfe.govt.nz/).

[38] Evison, 2017.

be expected to significantly increase the emissions price faced by fossil emitters, all else being equal.[39] Overall, the combination of no forest offsets, limited access to international units and auction revenues recycled to commercialise negative emissions technologies at scale would provide an unambiguous signal that deep and rapid cuts in gross fossil emissions are needed.

This combination of policies would help steer and accelerate New Zealand's transition towards a genuinely zero fossil carbon dioxide economy sometime in the second half of this century. How far down that transition pathway we might be in 2050 will depend on the ambition of succeeding emissions budgets. That will be a matter for our elected representatives acting on the advice of the Climate Commission. But a 50 per cent reduction in gross carbon dioxide emissions would be a more significant achievement than a net zero accounting 'triumph' in which recourse to forest sinks leaves gross emissions still at, say, 60 per cent of their current level.

Following the alternative approach outlined here, demand for forest offsets would come from biological emitters instead of fossil emitters in the NZ ETS. Land use change would be driven largely by landowners seeking to rebalance the natural capital on which they depend, rather than a completely external grab for 'sink space' by the fossil economy.

New Zealand is not exactly short of land. But making all land potentially available for storing carbon (as a substitute for not emitting it) will inevitably limit land use choices and options. Given the uncertainty that climate change poses for future land use, retaining land use flexibility will be important. However, as the Forestry Reference Group has recently noted: "… forestry is inflexible: trees grow slowly and forest management cannot respond quickly to market changes."[40]

A different dynamic is at work if only biological emissions can be offset with trees. In this case, offsetting will be at the expense of land used for farming and the source of emissions. Increases in the efficiency of emissions per unit of output would be needed to increase agricultural output. Otherwise there would be a self-limiting demand for more land for forest planting.

Placing biological methane and nitrous oxide emissions together with forest sinks in the same policy 'basket', separate from fossil emissions, would underscore the fact that these biological sources and sinks are often co-produced and co-managed in New Zealand landscapes.[41] Depending on how any such regime was incentivised, this could awaken a new attitude to tackling climate change (and other environmental challenges) on the part of landowners.

Treating these gases together can, therefore, help to optimise both economic and environmental outcomes, and provide the basis for a more landscape-based approach to managing the impact of New Zealand's land-based sectors within the biological cycles.

[39] The fossil emissions price would increase assuming that the price ceiling was increased or removed.

[40] Forestry Reference Group, 2018, pp.2-3.

[41] Biological methane from waste could also be included.

6 Making sense of the two climate policy approaches at the landscape level

Key points

- The reach of climate policy will be far greater than just reducing and mitigating emissions. It will drive changes right across Aotearoa New Zealand's landscapes. The Hurunui catchment provides a case study that illustrates the extent of land use change that may be expected.
- Changes in land use will have significant implications for the supply of ecosystem services in the Hurunui catchment. Some of the impacts on ecosystem services will be positive, others negative.
- The impact on ecosystem services has an important distributional aspect with many of the gains in these services occurring at the regional level, but losses impacting on private landowners.
- By limiting the fossil sector's access to offsets from reforestation, the alternative approach described here opens up the possibility of policies that can promote the co-management of biological sources across rural landscapes.
- In following such an approach, decisions about land use change would lie with the communities that live in them, and make room for a more complete consideration of the impacts of those decisions.

It is one thing to illustrate the possible outcomes of different climate policy approaches at the national level. But people live and work locally and when significant land use changes are in the balance it is useful to try to downscale the analysis to the local landscape level.

To do this, a case study was undertaken of what the two climate policy approaches would mean for the Hurunui catchment in the Canterbury region. The case study comprised both modelling and on-the-ground interviews to provide a more nuanced understanding of the potential effects on this rural community. Choosing a catchment in this region made particular sense given the significant land use change modelled to occur in this region with climate policy.

This analysis set out to make sense of the economic and environmental impacts highlighted in chapter five. These go well beyond climate change mitigation and entail trade-offs with other environmental and economic objectives.

Many of the benefits and costs that the different approaches throw up can be characterised using the ecosystem services framework. Ecosystem services are the goods and services that ecosystems provide that support wellbeing.

Ecosystem services are often categorised into three types: provisioning, cultural and regulating services.[1] Provisioning services are the products obtained from the landscape, such as wood, meat and water. Ecosystems and landscapes may also provide valuable cultural services such as recreation, biodiversity, conservation and aesthetic enjoyment. Some ecological processes provide regulating services such as water purification and land stabilisation. These three categories are used to describe the changes in overall ecosystem services that could be expected under the two approaches.

Armed with these insights, this part concludes with some thoughts on how a more integrated, landscape-based approach to policy development might better integrate multiple environmental objectives in a way that can engage the communities that live in them.

Hurunui catchment case study

The Hurunui catchment is located in North Canterbury and covers a total area of 2,671 square kilometres. The catchment area is primarily rural with sheep and beef farming and dairying being the predominant land uses in the middle and lower catchment, and the dominant forms of economic activity.

The Hurunui catchment also provides a range of cultural services. For example, the Hurunui River is one of Canterbury's most iconic rivers and provides many recreational opportunities, such as fishing and kayaking, as well as biodiversity conservation. In terms of cultural importance to Māori, historically the wider Hurunui district was used for settlement and resource gathering by Ngāi Tahu. The area also contains a number of former pā sites, and the river channels and coastlines provided a source of mahinga

[1] A fourth category, supporting ecosystem services, was not considered in this analysis as these services facilitate the provision of the other ecosystem service categories rather than make a direct contribution to wellbeing.

kai. Resources and significant sites in the area are taonga to Ngāi Tahu who play a kaitiaki role in protecting the area for future generations.

The Hurunui catchment, and in particular the Hurunui River, also provide some regulating services, including the removal of pollutants from land use activities. However, the intensification of land use activities and resulting non-point source discharge means that the services the river used to provide have been compromised by algal blooms.[2]

Source: Dirk Pons

Figure 6.1. The Hurunui catchment has a long history of occupation and use, first by Ngāi Tahu, then European farmers and settlers. The catchment and river provide a range of benefits in the form of ecosystem services, including agricultural production, biodiversity conservation, recreation and water purification.

The following provides an overview of land use change in the Hurunui catchment under the different climate policy approaches using the same modelling applied in chapter five. Figure 6.2 approximates current land use in the Hurunui catchment based on modelled projections for 2018. The modelled results show that in 2018, sheep and beef farming accounts for a significant proportion of the catchment land area.[3] Other important land uses include dairying and some forestry.

[2] Ausseil, 2010.

[3] Note that Figure 6.2 represents modelled land use in 2018 rather than actual land use in the Hurunui catchment, therefore some differences in represented land use will exist. Also note the modelling only considers the potential impacts of different emission prices on land use within the Hurunui catchment. Therefore, the modelled land use change and inferred impacts on ecosystem services do not explicitly account for existing policies relating to land use change and environmental management.

Current modelled land use patterns show dairy farming located in the middle and lower reaches of the catchment with forestry heavily concentrated in the middle of the catchment. In contrast, sheep and beef farming shows a more dispersed spatial pattern throughout the catchment. As noted in chapter five, the model is not set up to explicitly model horticulture, so its spatial extent is artificially predetermined based on key assumptions.[4] In reality, horticultural land area shown in figure 6.2 is occupied by a mixture of dairy, and sheep and beef farms.

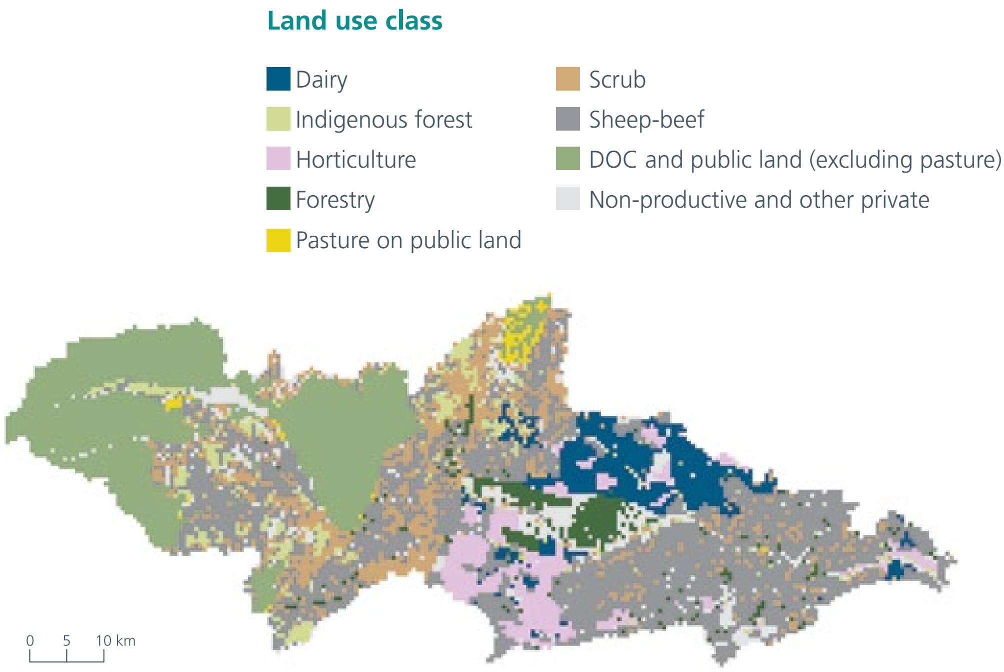

Figure 6.2. Map of modelled land use in the Hurunui catchment in 2018.

Current approach in the Hurunui catchment

Figure 6.3 illustrates modelled land use patterns within the Hurunui catchment in 2075 based on the current approach. Under this approach, all sources and sinks are fully substitutable and subject to a single emissions price.

The modelling shows that in aiming for a net zero emissions target, sheep and beef farming will decline by 55,800 hectares, from 93,100 hectares in 2019 to 37,300 hectares in 2075. This decline corresponds with an increase in forested area by 86,000 hectares, from 10,100 hectares in 2019 to 96,100 hectares by 2075. Of this, plantation forests will cover 64,100 hectares with the remainder in continuous cover native forests.[5]

[4] These assumptions were incorporated in the modelled output shown in figure 6.2, which approximates land use in the Hurunui catchment in 2018. Consequently, figure 6.2 will not provide an accurate depiction of the extent of horticultural land in the catchment.

[5] In line with the national level modelling assumptions, an assumption was made that plantation forests in the Hurunui catchment make up two-thirds of the reforested area, with native continuous cover forests comprising the remainder.

In 2075, land use in the catchment is markedly different. The land area previously subject to sheep and beef farming has largely been converted to forestry with only fragmented areas of sheep and beef farming remaining. This can easily be observed in the upper portion of the catchment with the almost total conversion of scrub and sheep and beef farming to forestry, which would be both plantation and native forests. Native forests, if planted, would be expected to be in the upper catchment, as this spatial area would likely be less economic for plantation forests.

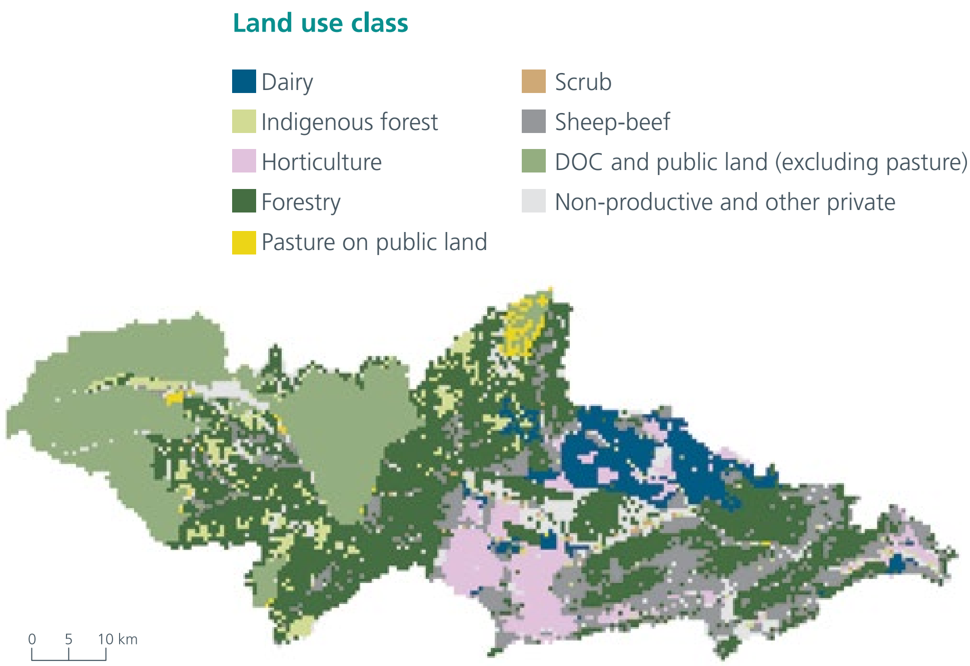

Figure 6.3. Map of modelled land use in the Hurunui catchment in 2075 under the current approach.

Alternative approach in the Hurunui catchment

The alternative approach was modelled assuming a target of either a 20 per cent or 100 per cent net reduction in biological emissions below 2016 emissions levels. Under the alternative approach, biological sources and sinks are not substitutable with fossil carbon dioxide emissions and are subject to two separate emissions prices.

Figure 6.4 illustrates the extent of land use spatially within the Hurunui catchment with the implementation of the alternative approach with a 20 per cent net reduction in biological emissions. In this scenario, the projected area under sheep and beef farming falls by 18,000 hectares from 92,800 hectares in 2019 to 74,800 hectares in 2075. Forestry increases by 22,000 hectares from 10,100 hectares in 2019 to 32,100 hectares by 2075. Plantation forests account for 21,400 hectares with the remainder composed of native forests.

Relative to land use under the current approach in 2075, the alternative approach shows limited conversion of scrub and sheep and beef farms to forestry. The smaller decline in sheep and beef land use results in an additional 37,500 hectares of sheep and beef farming in the catchment compared to the current approach in 2075. The area subject to reforestation only accounts for about one-third of the area attained under the current approach in 2075. However, larger pockets of forestry can now be observed in the middle and upper reaches of the catchment relative to the 2018 situation. This pattern also holds for scrub.

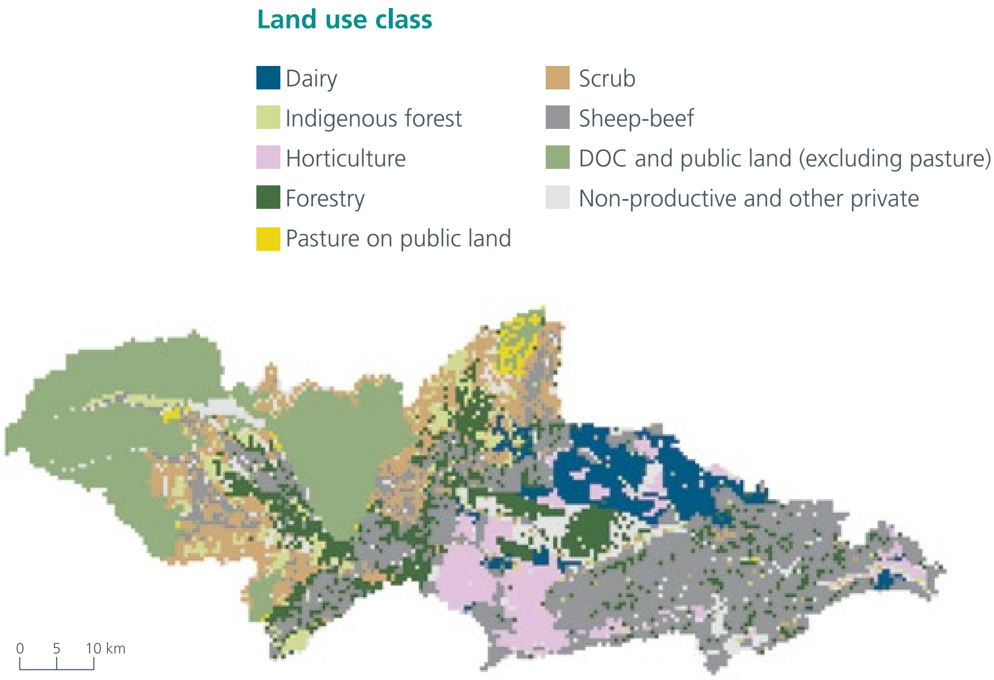

Figure 6.4. Map of modelled land use in the Hurunui catchment under the alternative approach with a 20 per cent reduction in net biological emissions in 2075.

Figure 6.5 illustrates spatially the land use modelled to occur in 2075 under the alternative approach with a 100 per cent reduction in net biological emissions. In this case, the area under forestry increases by 60,300 hectares from 10,100 hectares in 2019 to 70,400 hectares in 2075. Conversely, the area under sheep and beef farming in the catchment experiences a sustained decrease of 36,300 hectares from 92,900 hectares in 2019 to 56,600 hectares in 2075.

In terms of the spatial land use patterns, this variant of the alternative approach depicts greater levels of forestry conversion from land previously allocated towards scrub and sheep and beef. Relative to the 20 per cent variant, forestry covers an additional 38,300 hectares while land use under sheep and beef farming decreases by 18,200 hectares by 2075. However, in neither variant is the scale of land use change as extensive as that experienced under the current approach.

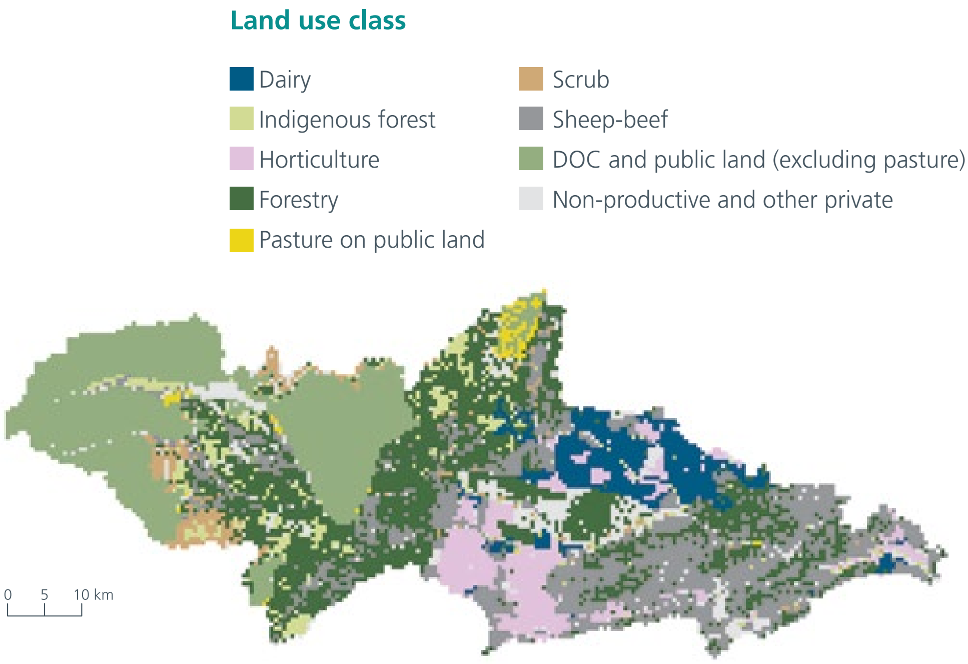

Figure 6.5. Map of modelled land use in the Hurunui catchment under the alternative approach with a 100 per cent reduction in net biological emissions in 2075.

Figure 6.6 shows the change in land use over time for both the current and alternative approaches for sheep and beef farming, forestry and scrub. As noted previously, dairying and horticultural land use are modelled to be relatively unresponsive to climate action. However, it might be expected, given the availability of water and the land use capability in the catchment for dairy, that an increasing emissions price would shift dairy to horticultural land uses, rather than forestry.

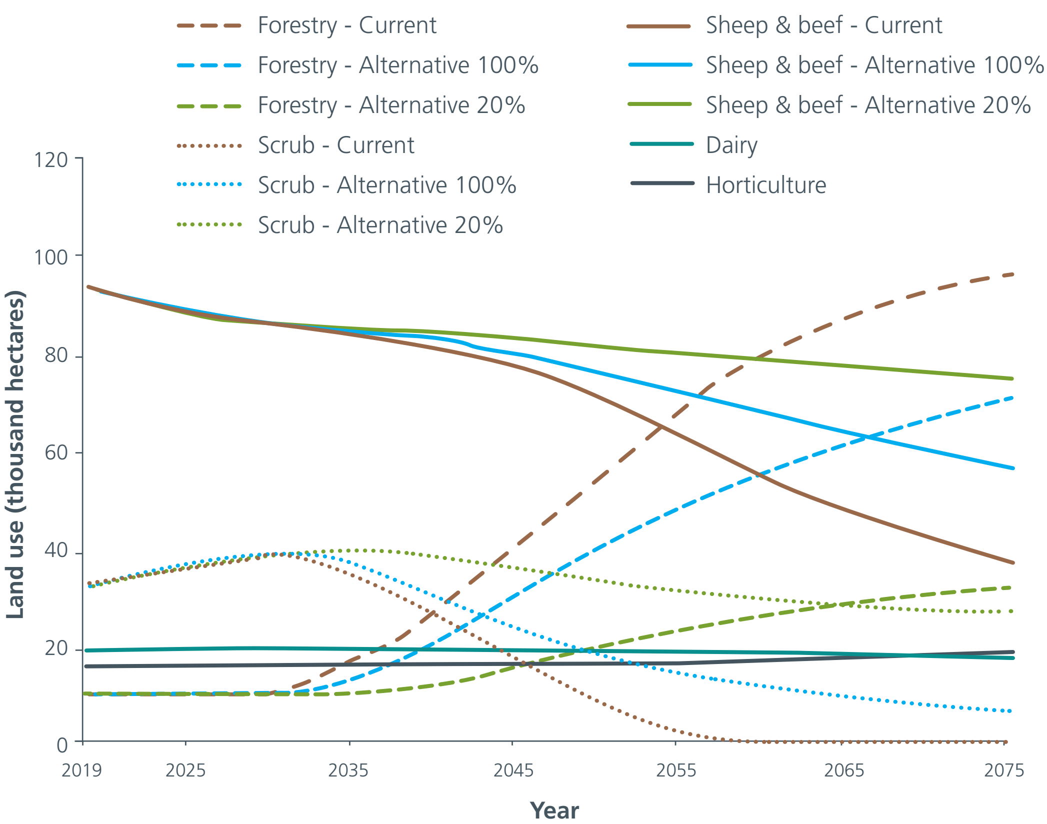

Figure 6.6. Land use over time (2019–2075) in the Hurunui catchment under the current approach and alternative approach with a 20 per cent and 100 per cent reduction in net biological emissions.

Figure 6.6 illustrates that forestry (i.e. native and plantation forests combined) will become the dominant land use in the catchment in the second half of this century for both the current approach and the alternative approach with a 100 per cent reduction in net biological emissions. However, sheep and beef farming is projected to remain, as it is today, the dominant land use in the Hurunui catchment under the alternative approach with a 20 per cent reduction in net biological emissions. As dairying and horticulture exhibit a similar land use pattern over time across the different climate policy approaches, only land use figures relating to the current approach were included.

Figure 6.6 also indicates that forestry conversion is likely to prioritise scrubland first. This is illustrated by the relatively rapid initial decline in scrub area accompanied by only a small decline in sheep and beef, which becomes more gradual over time.

Assessment of ecosystem services from climate policies

Many ecosystem services are not bought or sold in the marketplace. We lack monetary values for many of them. But that does not mean they have no value – quite the contrary.

This section provides a qualitative assessment of the impact of projected land use change on the provision of ecosystem services in the Hurunui catchment. Ideally, quantitative analysis in the form of the monetary valuation of these services would be available to assess the relative magnitude of ecosystem services from land use change induced by climate policies. However, a quantitative analysis is not conducted here for two reasons.

First, there is ongoing debate regarding the validity and appropriateness of assigning dollar values to ecosystem services, particularly for some cultural services. The ecosystem services framework does not perfectly reflect the way in which people view the world, as the framework compartmentalises the services and fails to illustrate the connectivity and complexity of ecosystems.[6]

Second, and more practically, the limited availability of monetary values from studies specific to New Zealand means that not all changes in the provision of ecosystem services are able to be valued.

Agricultural and forest production in the Hurunui catchment

Table 6.1 provides an indication of the change in agricultural production in the catchment in terms of stock units relating to sheep and beef farming and the number of hectares of forest harvested.

Table 6.1. Table of modelled agricultural production in the Hurunui catchment under the different climate policy approaches.

Agricultural production in the Hurunui catchment				
	2019	2030	2050	2075
Current approach				
Forestry area harvested (hectares)	0	80	30	1,470
Sheep-beef stock units	266,500	257,500	244,500	187,600
Alternative approach (20 per cent)				
Forestry area harvested (hectares)	0	80	0	780
Sheep-beef stock units	266,900	257,900	254,900	243,900
Alternative approach (100 per cent)				
Forestry area harvested (hectares)	0	80	30	1,150
Sheep-beef stock units	266,500	257,600	249,800	221,500

[6] Harmsworth and Awatere (2013) recommend that cultural values should underpin all ecosystem services and not be categorised as only a cultural service.

Under the current approach, the area of forestry harvested increases by 1,470 hectares between 2019 and 2075. The number of sheep and beef stock units in the catchment declines by 78,900 units. This change in agricultural production is more modest under the alternative approaches.

Under the variant with a 20 per cent net reduction in biological emissions, the forestry area harvested increases by 780 hectares between 2019 and 2075. Stock units fall by 23,000 units over the same period. In contrast, the impact on agricultural output is greater under the alternative approach with a 100 per cent net reduction in biological emissions target. Under this scenario, the area of forest harvested increases by 1,150 hectares with stock units reduced by 45,000 units by 2075.

The significant expansion of plantation forestry within the catchment under both climate policy approaches will increase the supply of forest products, including logs, timber and fibre. This increase in forest products could also support climate change mitigation if they are used to displace more fossil carbon-intensive products like cement, steel and fossil fuels. This will depend, in part, on the price of fossil emissions units.

In contrast, the establishment of native forests with limited production potential would be at the expense of plantation forest and agricultural products. Furthermore, all reforestation will come at the expense of sheep and beef farming. The land area under sheep and beef farming is projected to decline under both climate policy approaches leading to reductions in the supply of agricultural products, such as meat and wool.

Forestry can also reduce water yields as increased evapotranspiration means less water will flow to downstream segments of the catchment. This can have a detrimental impact on river flow regimes and potentially conflict with land use activities dependent on irrigation.

The impact on local employment from the projected land use change could be significant. Agricultural employment is typically localised, where farmers and farm workers live on the landscape where they produce meat, crops and milk. In contrast, forestry workers and forestry-related processing jobs are typically concentrated in larger regional centres.[7] Accordingly, a decline in sheep and beef farming and an expansion of plantation forests might be expected to result in fewer primary sector employment opportunities and fewer opportunities for business services permanently located in the Hurunui catchment.

The potential employment impacts also have a social dimension. Rural depopulation can have a flow-on impact on the viability of community-based health and education services and undermine social cohesion and a sense of community.[8] As the Forestry

[7] Fairweather et al., 2000.

[8] Williams and Schirmer, 2012.

Reference Group has noted, these social issues are likely to be particularly significant for Māori who are "over-represented in remote communities where both Māori and non-Māori marginal land is being farmed and supplementing local incomes."[9]

The availability of forestry jobs relative to agriculture may also be less continuous. Unlike agriculture which provides work year round, forestry work may follow less even employment patterns with significant gaps in employment between establishment and harvesting periods. Furthermore, the delayed return on investment with forestry suggests that certain landowners may not derive any direct or immediate benefit. This problem was highlighted specifically in discussions with community members in the district. All of these patterns lead to genuine concerns regarding the employment of farmers, agricultural workers and downstream business services in the catchment.

Cultural services in the Hurunui catchment

Land use change within the Hurunui catchment will also affect the opportunities for recreation, biodiversity conservation as well as aesthetic values. Forests provide a range of recreational opportunities, including walking, mountain biking, horse riding and hunting. These are often highly valued.[10]

While some new reforestation could be expected to provide an increase in recreational opportunities, the marginal value of new opportunities could be expected to diminish rapidly especially at the high levels of reforestation projected under the current approach. For example, there is likely to be a limit to the number of new walking and mountain biking tracks that will add sufficient value for locals and visitors to justify the cost of setting them up and maintaining them.

On balance, it is likely that recreational services would increase under both climate policy approaches. However, it would be surprising if the widespread reforestation projected to occur in the Hurunui catchment under the current approach would provide notably more recreational opportunities than the alternative approach.

In terms of biodiversity conservation, native forested areas can obviously contribute to biodiversity through the species planted on the landscape and the habitat these species provide for native fauna.[11]

Exotic plantation forests can also provide a home for native fauna, and the value of this to local communities can be significant.[12] Unlike recreation, the value of improving biodiversity is likely to grow as the scale of forestry grows, at least up to a point.[13]

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[9] Forestry Reference Group, 2018. p.4.

[10] For example, recreational services from forests have been estimated for Whakarewarewa Forest in Rotorua to be $56 and $40 per visit (figures adjusted to 2018 NZD) for mountain bikers and walkers respectively. See Dhakal et al., 2012.

[11] The value of biodiversity conservation can be high. One study estimated that a typical respondent would be willing to pay $52 (figure adjusted to 2018 NZD) per year for improvements to biodiversity resulting from native reforestation on private land across New Zealand. See Yao and Kaval, 2008.

[12] For example, one study estimated the conservation values associated with a proposed biodiversity enhancement programme in New Zealand's production forests. Households were willing to pay $21 (figure adjusted to 2018 NZD) per year for an increase in the abundance of the New Zealand bush falcon in production forests. See Yao et al., 2014.

[13] Liekens and de Nocher, 2014.

This is because the higher the forested area, the greater the reduction in forest fragmentation, which is often a stumbling block to enriched biodiversity.

However, this effect may be strongest in native forests. Monocultural, plantation forests may be less conducive to biodiversity conservation, although some native species can do well in such habitats (see figure 6.7). Furthermore, stands can contribute to the spread of invasive wilding pines in the landscape, which can compete with native species.

Finally, improved biodiversity is likely to be unevenly distributed across the Hurunui catchment. For example, lowland areas previously subject to pastoral land use might be expected to yield greater improvements in biodiversity when forested compared to other less well watered or less fertile parts of the catchment. But the higher value of these lowland areas means they are more likely to be planted in commercial plantation forests than native ones.

Source: Bruce McKinlay

Figure 6.7. Many native species can make their homes in plantation forests, including the native New Zealand falcon, kārearea. Careful forest management, such as harvesting practices and pest control operations are critical however, to ensure native species can survive and flourish in such landscapes.

On balance, it is likely that biodiversity conservation would increase under both climate policy approaches, especially where native forest regenerates or is planted. However, the vast projected increases in monocultural plantation forests may not provide significant improvements in biodiversity, as while these forests can provide habitat for some native species, they also come with significant ecological risks.

Large scale reforestation is also likely to have impacts both positive and negative on aesthetic values. Engagement with some members of the rural community revealed a clear preference for retaining the aesthetic of the rural agricultural landscape and concern for what large monocultural plantations would mean for the landscape. Only the alternative approach, which can retain sheep and beef farming as the dominant land use, would conserve a rural agricultural landscape.

Regulating services in the Hurunui catchment

Land use change in the Hurunui catchment will affect the provision of regulating services, including water purification and land stabilisation.

Reforestation can lead to improvements in water quality through reductions in sediment loading from land stabilisation on steeper gradients. Lower sediment inputs result in better water clarity and less smothering of stream and river beds, and streams in areas under a forestry canopy typically have better water quality compared to those in pastoral settings. Streams and rivers with less sediment also have greater channel capacity and are less prone to flooding in high rainfall events.

Freshwater ecosystems can also benefit from less nutrient leaching from forested land due to reduced nutrient input and greater interception of nutrient runoff. However, improvements in water quality are also dependent on the spatial distribution of reforestation relative to dairying land use within the catchment.

The current approach results in large scale reforestation across the catchment, including areas located downstream of dairy farming. The alternative approach results in relatively limited reforestation in the middle and lower segments of the catchment where dairying is located. Consequently, any improvements in water quality are likely to be greatest under the current approach due to both the scale and location of forest stands.

Improvements in water quality can be expected to have flow-on benefits with improved swimmability, biodiversity conservation and values important to Māori, such as mahinga kai and taonga species. However, despite these potential improvements, disturbances caused by the logging of plantation forests could be expected to periodically decrease water quality as well. Heavy rainfall in the post-harvest period can deposit large amounts of sediment and nutrients into waterbodies and can also see large amounts of harvest debris being washed downstream.

Reduced water availability in forested catchments can exacerbate water quality during periods of low flows, particularly in water-stressed tributaries. On balance, large scale reforestation can be expected to improve water quality under all climate policy approaches provided good forest management is practiced. However, these gains might be offset, at least partially, by reduced water availability. The current approach is likely to involve the most significant trade-offs between water quality and availability given the scale of reforestation projected.

These trade-offs will be progressively exacerbated by the impacts of climate change. In the case of the Hurunui catchment, climate projections indicate that the catchment could experience additional levels of water stress due to an increase in average temperatures and windier conditions. This could pose challenges for forestry, as well as more intensive land use activities.

Finally, changes to agricultural land use patterns and management practices in response to climate policy can also be expected to yield a number of changes to water quality. These are expected to be largely positive. For example, practices that reduce emissions through the more efficient application of fertiliser could reduce nitrogen runoff to waterways.

Distributional impact in the Hurunui catchment

The projected land use change in the catchment is based on private landowners responding to economic incentives provided by an emissions price. While landowners make a choice regarding land use options based on the incentives they face, land use change will still impose wider costs and disruption on rural communities. However, this transition will occur over time and provide opportunities for these communities to adapt existing economic and social structures to changing land use patterns.

Overall, both approaches are expected to result in considerable change in ecosystem services in the Hurunui catchment over time. The current approach is likely to result in the largest changes. While some of these changes will be positive, others may be negative and further exacerbated by climate change.

Regardless of the approach taken, it is true that many of the gains in ecosystem services with large scale reforestation would likely be distributed across the wider Canterbury region, rather than captured by private landowners. In contrast, the costs of land use change in the Hurunui catchment are mainly clear trade-offs between agricultural and forest products. The costs of these trade-offs extend to the community level where land use change to forestry may be detrimental to employment and other socio-economic dimensions of the rural community.

The scale, tenure and ownership of forestry operations will play a key role in determining the socio-economic impact of large scale reforestation and its acceptance by rural communities. Evidence from Australia indicates that smaller scale forestry that is better integrated with current farming practices has a much less limited impact on rural communities and socio-economic disruption, while still providing for improved ecosystem services.[14]

It is with the alternative approach that we are more likely to see these opportunities arise. And it is with this approach that a more diverse set of land use activities is able to remain in the landscape over time.

[14] Schirmer et al., 2016.

Shifting our attention to landscapes

If we follow the current approach to climate policy, we can expect large-scale reforestation to help achieve net emissions neutrality. We know this will have a significant impact on rural landowners and communities. It may also be at the expense of greater progress on reducing gross fossil emissions.

As the examination of the Hurunui catchment demonstrates, reforestation can provide more than just climate mitigation. Policymakers need to see the landscape as more than just a place for storing carbon but instead a place from which a range of inter-related environmental, cultural, social and economic services are derived.

Thinking about how policies will play out at the scale of the landscape makes sense. It is at this scale that productive systems draw most directly on ecosystem services and the trade-offs between these services become apparent.

Relying on a single emissions price delivered by the NZ ETS to drive the reallocation of resources over millions of hectares runs the risk of previous broad brush interventions that have set in train earlier transformations of our landscapes. Not all the outcomes would necessarily be negative, but in the absence of equivalent prices on an array of natural assets, like soil and water, not to mention cultural and recreational values, there is a real risk that the landscape's primary value becomes externally determined by climate mitigation policy alone.

This draws attention to a much wider challenge that the regions are grappling with. Under the Resource Management Act 1991, councils are required to be enabling local communities to provide for their wellbeing, while safeguarding the life-supporting capacity of air, water, soil, and ecosystems, minimising negative environmental impacts and thinking long term about the sort of landscapes future generations will inherit.[15]

But there is inevitably a tension between the delivery of those environmental outcomes at the level of the landscape and the plans of individual landowners. Environmental and ecological processes don't recognise boundary fences. To add further complexity, landscapes are subject to a climate that is changing, and the rate and magnitude of this change is highly uncertain.[16] So what we do know about these landscapes today will not necessarily hold true in the coming decades.

The activities of one landowner or stakeholder are rarely independent of the activities of others. The challenge of responding to an emerging crisis in water quality over the last decade has revealed the need to engage entire communities within catchments

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[15] Resource Management Act 1991 – Part 2, Section 5(2).

[16] There is considerable uncertainty regarding the magnitude of change relating to extreme natural events, including sea level rise and the frequency of droughts, floods and fires. Perhaps one of the most significant uncertainties is in just how much mitigating action will be taken by the world in the coming decades, which will determine the magnitude of change the world will see. For the time being, this is an uncertainty that no amount of research can resolve (Ministry for the Environment, 2018b).

and sub-catchments. Responding to climate change can only reinforce that need because talk of getting the 'right tree in the right place' means considering the consequences of those decisions beyond property boundaries and under a changing climate; that will become increasingly difficult.

Landscape approach

A landscape approach to developing policies would aim to integrate all that we know about environmental processes at the landscape scale with bottom-up, grass roots knowledge.[17] It would focus on giving those who live there the incentives and the means to start thinking about ways to do more than just balance sources and sinks across the landscape, and also address other environmental and socio-economic concerns in parallel.

The Māori concept of mauri can help to reinforce a landscape-based approach. Mauri is defined as the life-force or energy of all animate and non-animate things. By stressing the interdependency and interconnectedness of all those elements that make up the landscape, mauri comes to the aid of a more holistic view of what environmental policy should be trying to achieve. The whole is more than the sum of its parts.[18]

There is already a range of government and community-based initiatives underway that are aligned with, or could form the basis of, a landscape approach. Central amongst these is the Government's current freshwater reform programme, which identifies that a key driver of declining water quality has been the expansion and intensification of the pastoral sector, and particularly nitrogen losses from the dairy industry.[19] Policies and other tools such as the freshwater reforms that acknowledge Te Mana o te Wai[20] and require substantial reductions in nutrient losses to waterways from key sources have the potential to also significantly reduce emissions of methane and nitrous oxide as a co-benefit, and lead to more diverse and resilient landscapes.

Encouragingly, the Government's discussion document signals that the government is thinking more broadly than just freshwater, and notes: "We are also supporting our land-based sector to transition towards sustainable land use. Our vision goes beyond healthy water – we are working towards an environmentally sustainable, high-value economy that supports the wellbeing of all New Zealanders."[21] To make this a reality and get beyond the expression of laudable vision statements will require engagement with real communities on the ground.

[17] Scherr et al., 2012; Sayer et al., 2013.

[18] As an example, the existing Amuri Irrigation scheme draws water from both the Waiau and Hurunui Rivers. "For tāngata whenua, avoiding the unnatural mixing of waters is fundamental to the protection of mauri in waterways. Transferring water from one catchment to another or mixing different types of water through flow augmentation, tributary transfers and out-of-catchment transfers means that the life supporting potential of the receiving water is potentially compromised (i.e. it may no longer have the same life giving potential as it would if it were left in its original state)." Ngāi Tūāhuriri Rūnanga et al., 2013. p.92.

[19] Ministry for the Environment and Ministry for Primary Industries, 2018, p.9.

[20] Te Mana o te Wai is the integrated and holistic wellbeing of a freshwater body (NPS-FM).

[21] Ministry for the Environment and Ministry for Primary Industries, 2018, p.5.

To achieve any sort of acceptability, such a landscape approach must begin with willing landowners, tangata whenua and the community, as they take ownership of the decisions and exercise their rangatiratanga. It needs to provide a platform for discussions that capitalises on the shared pool of knowledge and experiences from people living in those landscapes to begin to map out a future landscape that fits the needs of the community.

Given the significant extent of Māori stakes in farming and forestry, these interests and their future evolution will play a critical role in any responses to an integrated, landscape-based approach to climate mitigation and adaptation. But beyond actual ownership stakes, the landscape is saturated with names and lore that spring from a long association with the landscape. This deeply felt affinity with the land is an invaluable resource if we are to respond intelligently to the challenge of managing environmental change at the level of the landscape.

Examples of community led initiatives along landscape lines are playing out in different corners of New Zealand right now. While they are often focused on a single policy objective, the outcomes will inevitably be seen in other areas. Efforts to restore water quality to date have been largely based on fencing and restoration of riparian margins, and in doing so, communities are effectively providing vegetated corridors across rural and urban landscapes supporting biodiversity.[22]

As a means to promote action on water quality, collectives are being led from the ground up in many places. The calibre of applicants for the New Zealand River Awards that recognise the stream restoration projects going on throughout the country is testament to this.[23] Other initiatives, such as the Greater Wellington Regional Council's Whaitua[24] and Environment Canterbury's Zone Committees[25] have been catalysed by regional government to forge collective agreement on appropriate nutrient discharge limits.

Likewise, the Predator Free 2050 programme has boosted public engagement in support of biodiversity conservation. Iwi, community groups, tramping clubs and volunteer organisations are maintaining trap lines for feral pest management, and restoring habitat across public and private land. Collectives tackling more ambitious goals are beginning to form. Te Manahuna Aoraki is a partnership between the Department of Conservation, NEXT Foundation, Te Rūnanga o Arowhenua, Te Rūnanga o Waihao and Te Rūnanga o Moeraki with 14 high country station landowners in the Mackenzie Basin. Working across both private and public land management units, the group aims to rid 310,000 hectares of pests and weeds.[26]

Recognising the value of volunteer hours in these activities, regional councils are beginning to implement strategies to support voluntary organisations. Regional

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[22] A policy outlined in the Draft National Policy Statement for Indigenous Biodiversity (Biodiversity Collaborative Group, 2018, p.70).

[23] New Zealand River Awards. https://www.cawthron.org.nz/foundation/nz-river-awards [accessed 5 March 2019]

[24] Whaitua Committees. http://www.gw.govt.nz/whaitua-committees/ [accessed 5 March 2019]

[25] Canterbury Mayoral Forum, 2009.

[26] Te Manahuna Aoraki Project. https://www.temanahunaaoraki.org [accessed 5 March 2019]

biodiversity hubs have been established by the Taranaki Regional Council, Wild for Taranaki,[27] and in the Bay of Plenty, the Bay Conservation Alliance.[28] The roles of these hubs includes providing advice on restoration, health and safety training, support in funding applications and reporting, financial services and coordinating collaboration among groups.

A critical component of this process is ensuring that rural communities have access to locally relevant and unbiased information to assist in evaluating the options for land use change. Trusted advice on alternative feed crops, forestry options, or enhancing biodiversity needs to be made accessible before uptake will occur. Consultants in agricultural, horticultural, forestry, and ecological systems are available commercially to fill this role once decisions on land use are made, but the step prior to that, advice on the type of land use, is lacking.

Source: James Anderson, World Resources Institute

Figure 6.8. Adopting a landscape approach allows for a more diverse set of land use activities, enhancing the resilience of rural communities to future environmental and economic disruption.

[27]Wild for Taranaki. https://www.wildfortaranaki.nz/ [accessed 5 March 2019]

[28]Bay Conservation Alliance. https://www.bayconservation.nz/ [accessed 5 March 2019]

A high level advisory service within regional or central government agencies to conduct land use capability assessments and who carry a basic understanding of a range of land use options could fill this niche. This service, not wholly unlike the Advisory Services Division operated through successive national agricultural agencies from the late 1800s to 1995,[29] could provide an industry independent voice to assist land managers and drive landscape scale decision making.

In addition to trusted advice, there are personal factors, including broader societal values and perceptions of practices by farmers and peer groups.[30] This implies that programmes intended to enhance the adoption of environmental management practices need to go beyond the simple provision of technical information. Consideration needs to be given to the 'human' element which includes understanding landowner perceptions and investing time and resources to establish a sense of whanaungatanga, trust and social connections between landowners.

A better understanding of land capability and land uses and practices that enhance resilience could lead to better environmental policy and management. If we know, for example, that fine textured soils are better at attenuating nitrogen and we know where those soils are,[31] nutrient leakage management can be more targeted. If we know that alternative feeds, such as lucerne, can improve the growth rate of lambs and get them out the farm gate faster, we can make incremental reductions in biological emissions.[32] And if we know where vegetation can be best placed, and what species it should be composed of, land managers can significantly reduce the risks of pests, pathogens[33] or fire[34] spreading across landscapes.

These are fine-grained things, but no less valuable for that. And every land use change that is recommended has to carry the qualifier that as the climate changes, so will farming and forestry practice. Building adaptation into land use thinking and kaitiakitanga principles will be a crucial source of resilience in the future.

While there are sources of funding to support communities working together to promote biodiversity on private land,[35] water quality[36] and others to help assist with forestry establishment costs,[37] even large, one-off grants and incentives are unlikely to generate the fundamental shift required across our landscapes to integrate multiple,

[29] The advisory service, which functioned under a series of titles and government departments, ran research farms, training facilities and offered free advice (until its last few years as Agriculture New Zealand) on agricultural and horticultural practices (Peden, 2008).

[30] Biological Emissions Reference Group, 2018, p.5.

[31] Elwan et al., 2015.

[32] Moot et al., 2008.

[33] Jactel et al., 2017.

[34] Curren et al., 2018.

[35] Such as the Department of Conservation's Community Fund, amongst many others. https://www.doc.govt.nz/doc-community-fund [accessed 5 March 2019]

[36] Such as the Ministry for the Environment's Freshwater Improvement Fund. http://www.mfe.govt.nz/more/funding/funding-fresh-water/freshwater-improvement-fund [accessed 5 March 2019]

[37] Te Uru Rākau Forestry New Zealand funding and programmes. https://www.mpi.govt.nz/funding-and-programmes/forestry/planting-one-billion-trees/ [accessed 5 March 2019]

diverse environmental objectives in a cohesive manner.[38] But neither is a single emissions price determined by demand for a shrinking supply of NZ ETS units from the entire economy.

By contrast, an alternative approach that treats fossil emissions separately would give biological emitters clearer signals to optimise land uses to achieve multiple land management objectives. The revenue from the pricing of biological emissions can be partially hypothecated back to the landscapes and communities (e.g. supporting tree planting) where they originated.

Returning funds to the landscape which generated them is likely to significantly improve public acceptability of taking strong climate action on biological emissions. Indeed, hypothecating (i.e. earmarking) to the landscape communicates that the revenue recycled is being introduced for climate and wider environmental reasons, and not simply to raise additional revenue for government expenditure.

Revenue hypothecated to landscape-level projects would be applied to more than just climate change mitigation. They would, instead, be extended to the full range of ecosystem services provided by forests. This is akin to some of the proposed grants available under the One Billion Trees Fund,[39] but would be on a much larger scale.[40]

Some of the funds not allocated to landscape-level projects could be used to support the ongoing administration of the pricing instrument and national level funding in the research and development of mitigation options for biological emissions. One criterion for determining the appropriate split between funds being hypothecated locally and nationally for climate policy is the need to reduce gross biological emissions. If gross biological emissions remained high, then a greater proportion of the funding might be best allocated towards national level research.

The scale of the revenues is likely to be sizeable. For example, modelling the alternative approach in the Hurunui catchment suggested that between now and 2050, up to $640 million could potentially be available to the catchment that generated it, if these funds were returned to this landscape alone.

Redistributing funds to support forestry on the basis of the level of biological emissions produced in each landscape, would shift the type and location of trees within a landscape and the distribution of reforestation across New Zealand. Hypothecating revenues from biological emissions pricing for each landscape and for multiple environmental objectives would incentivise forest planting across most of New Zealand's landscapes rather than predominantly in Canterbury, Otago and Manawatū-

[38] An example of a more integrated approach being taken at the landscape level is the development of integrated farm plans developed by LUCAS Associates. http://www.lucas-associates.co.nz/carbon/integrated-farm-plan/ [accessed 5 March 2019]

[39] Te Uru Rākau Forestry New Zealand, 2018b. This programme provides additional grants for: forests planted on erosion prone land, and fencing and pest control in indigenous forest, and to the 'Trees that Count' programme run by Project Crimson Trust for community lead biodiversity restoration initiatives.

[40] The hypothecation of funds from climate policy is consistent with the Government's coalition agreement that states: "[i]f the Climate Commission determines that agriculture is to be introduced in the [NZ] ETS, then upon entry, the free allocation to agriculture will be 95 per cent but with all revenues from this source recycled back into agriculture in order to encourage agricultural innovation, mitigation and additional planting of forestry" (New Zealand Labour Party & New Zealand First, 2017, p.5).

Whanganui, which would be the case if climate change mitigation was the primary objective. The result would likely optimise the provision of ecosystem services and improve wellbeing to communities considerably as the benefits of these services typically accrue locally.

A programme where some of the financial risk is absorbed could incentivise land owners to experiment with more diverse farming methods. This could enable more flexible approaches to land use and promote the delivery of a wider range of ecosystem services.

Even a shift in emphasis from measuring productivity to pure farm profitability could steer practices away from emissions-intensive operations. Research from experimental farms throughout the country has demonstrated the emissions and nutrient leaching gains to be made through improved farm management lowering input costs, reduced stocking rates and improved genetics without decreasing farm profitability.[41]

Overall, the results from these studies suggest that reductions in biological emissions from farms in the range of 10 to 50 per cent below baseline levels are possible over time without changes in land use (see box 6.1). When diversification into alternative productive land uses is considered, larger reductions in emissions are possible – up to 10-fold reductions or more.[42]

[41] Note however, that some measures, including the use of dams and associated effluent ponds, which are intended to reduce nutrient runoff to waterways, may lead to additional methane being emitted.

[42] Clune et al., 2017; Poore and Nemecek, 2018.

Box 6.1. Potential for on-farm reductions in methane and nitrous oxide emissions[43]

New Zealand farms vary widely in their biological emissions – the highest emitting farms can produce around twice as much methane per hectare, and three times as much nitrous oxide, as the lowest emitting farms.[44] This reflects the variety of soils, climate, farm size, and farm type, and importantly, the way in which a farm is managed.

There is an increasing body of research showing that it is possible on some farms to reduce stock numbers and thus reduce greenhouse gas emissions, while maintaining or improving profitability. For example, one study estimated that lowering the stocking rate and increasing the milk production per cow could increase profits while reducing total biological emissions by up to 15 per cent in a model farm.[45]

In one case study of a Waikato dairy farm, the number of cows was reduced from 530 to 350 over a five-year period. A range of improvements to farm management led to lower input costs. Each cow became more productive, while the milk produced by the farm remained the same. The outcome was increased profitability, a small reduction in methane, a reduction in nitrous oxide of 20-30 per cent, and a reduction of nitrate leaching of 50 per cent.[46]

Another study looked at a range of options for improving productivity and simultaneously reducing greenhouse gas emissions on 29 Māori farms.[47] Options included changes to feeds, fertiliser application, stocking rates, and the stock mix. The use of feed pads, and planting trees – mānuka, pines, and cypresses – were also modelled.[48]

The modelling of changes to the management of the farms has generally shown the potential for relatively modest reductions in greenhouse gas emissions (5–10 per cent). However, in some cases, the modelling has shown potential for greater reductions in both biological gases, along with increased profitability.

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[43] Material drawn in part from the 2016 Parliamentary Commissioner for the Environment (PCE) report 'Climate change and agriculture: Understanding the biological greenhouse gases.'

[44] Kingi et al., 2015.

[45] Anderson and Ridler, 2010.

[46] Dewes, 2015.

[47] Journeaux et al., 2018.

[48] Journeaux et al., 2018. This study looked at a range of mitigation options and modelled the potential changes in production, total emissions, and emissions intensity per unit of milk or meat produced, along with the resulting profit.

A drive towards more diverse rural industries could spread the risk of losses from environmental disturbances by reducing susceptibility to any one climatic or economic stress. More diverse land uses could be expected to facilitate more species and genetic diversity in ecosystems, which could in turn reduce the risk of exposure to climatic and economic disturbances. This would be in contrast to the sort of large scale, monocultural plantation forests that the current approach could encourage. Viewed simply as carbon stores, these forests could be particularly vulnerable to pest and weed invasions, fire, droughts and other extreme weather events as the climate changes.

The preceding discussion does not pretend to do more than raise the possibility that maintaining a clear separation of the land-based sectors from the management of fossil emissions could facilitate different ways of pursuing both climate and other environmental and economic outcomes in tandem. More detailed thinking needs to be done by the policy community that must, in turn, listen to the communities whose landscapes are, for the moment, being seen as convenient carbon stores.

Reforestation has a bright future in many parts of Aotearoa New Zealand and can yield many benefits. But it needs to be pursued in a way that integrates water quality, soil erosion, biodiversity conservation and climate adaptation, as well as climate change mitigation with one another. The way in which climate policy develops could determine whether that happens or not.

Appendix one: Potential synergies and trade-offs for some on-farm mitigation options

Table A1.1 provides an overview of some of the key on-farm mitigation options currently available, or being actively researched, to reduce methane and nitrous oxide emissions here in New Zealand.[1]

When designing mitigation policies, policymakers need to be aware of potential synergies and trade-offs that exist between different mitigation actions. Because tackling climate change will be an ongoing, long-term issue, it is also necessary to assess how far away any promising new mitigation options are from becoming viable on the farm.

Table A1.1. Potential synergies and trade-offs for some on-farm mitigation options.

Mitigation option	Potential impact on biological methane	Potential impact on nitrous oxide	Availability/comments
Selective breeding for low-methane animals	Trials over 10 years have achieved around a 10% difference between high-methane and low-methane sheep	Minimal impact expected	No adverse impacts on productivity observed so far. Years from being integrated into existing genetic selection and breed improvement efforts
Low-methane feeds (e.g. brassicas, rape, high-fat ryegrass)	Brassicas and rape can reduce enteric methane emissions by around 25–30%, but can only be used at certain times of the year; high-fat ryegrass has reduced methane by 15–20% in laboratory trials	Under some conditions, switching to brassicas and rape can make fields wetter and boggier leading to increased N_2O emissions; there is some evidence of reduced nitrogen excretion associated with high-fat ryegrass	Some feeds available already. Genetically modified, high-fat ryegrass being field tested in the US. Legal and social license issues associated with the use of genetically modified ryegrass. Many years away
Smarter use of nitrogen fertiliser/ use of legumes in place of nitrogen fertiliser	Minimal impact expected	Reduced N_2O emissions associated with fertiliser use	Technology for smart fertiliser application available now. Planting of legumes also possible now. Would also reduce leaching of nitrogen into waterways[2]

[1] An evaluation of the strengths and weaknesses of the technological options for mitigating emissions from livestock was undertaken by the previous Parliamentary Commissioner for the Environment in 2016. Several assessments of the mitigation options available to New Zealand's agriculture sector have since been published including; Biological Emissions Reference Group (2018) and Gluckman (2018).

[2] Newell et al., 2011.

Mitigation option	Potential impact on biological methane	Potential impact on nitrous oxide	Availability/comments
Methane vaccine for livestock	Goal is to create a vaccine that reduces methane by 20%	Minimal impact expected	It has been demonstrated in laboratory conditions that antibodies can target and impact pure methanogen cultures, but a reduction in livestock has yet to be achieved. Likely to be many years before commercially available
Methane inhibitor for livestock	Methane reduced by 20–30% in trials	Small possible impact on nutrient digestibility[3]	Inhibitors are available and used overseas where livestock are housed and fed but likely to take at least another five years to develop a slow-release methane inhibitor suitable to give to livestock that mostly graze in paddocks as they do here in New Zealand.
Nitrification inhibitor for soils	Minimal impact expected	Can reduce N_2O emissions by 30–70% in field conditions, though the use of nitrogen inhibitors was halted in 2013 after trace residues were found in milk[4]	Nitrate leaching losses can be reduced by up to 35%, but may cause small increases in ammonia releases to air and ammonium/nitrate losses to water.[5] Available now – but controversy means use unlikely any time soon.
Restrictive grazing (removing livestock from the paddock at certain times of year)	Impact of housing animals for longer periods remains unclear – it could increase methane emissions from manure decomposing under anaerobic conditions, but also make it easier to implement a methane inhibitor in feed	Can reduce N_2O emissions from urine and dung deposited on the paddock by around 10% for dairy farms and 6% for sheep and beef farms[6]	Could also reduce loss of phosphorus and reduce release of sediment. Stand-off pads and herd houses are already used by some farms in New Zealand today, but caution is required as capital outlay is large and may lead to intensification. Possible now
Decrease stocking rates on farms	Reduced methane emissions	Reduced N_2O emissions due to fewer urine patches, lower manure production. In addition there may be lower fertiliser use for forage, and the elimination of intensive winter feeding operations on wet soils	Would also reduce leaching of nitrogen and phosphorus into waterways and reduce loss of sediment, but may have a negative impact on short-term profitability. Possible now

[3] Jayanegara et al., 2018.

[4] Talks are underway to establish international guidelines for acceptable levels of dicyandiamide (the active ingredient in nitrogen inhibitors) in food. This could result in nitrogen inhibitors being reintroduced in New Zealand by 2020 (Carbon News, 2018).

[5] Daigneault et al., 2017. Reference listed at bottom of p.182.

[6] Daigneault et al., 2017.

Appendix two: Technical modelling detail and assumptions

Technical detail of the LURNZ and ENZ models

The two models applied in this work were the Land Use in Rural New Zealand (LURNZ) model and the Energy and Transport New Zealand (ENZ) model. Both models break down the New Zealand economy into specific sectors.

The LURNZ model is a dynamic and spatially explicit model of land use for all private rural land in New Zealand, including all major land use sectors (forestry, dairy, sheep and beef farming, horticulture) and unproductive scrub. The LURNZ model can simulate land use changes in response to changes in emissions prices. The LURNZ model modelled biological emissions in terms of carbon dioxide equivalent using the GWP_{100} metric.

At the core of the LURNZ model are two sub-models that are econometrically estimated. One sub-model estimates dynamic land use responses and the overall amount of land use change at the national level to various drivers of change, including commodity prices. The other sub-model is a spatial model that determines the spatial location of land use change by relating land use choices to various geophysical characteristics of the land (e.g. slope, land use capability) and to proxies for the cost of market access, among other things. With the spatial projections of land use estimated, the LURNZ model determines the land production and associated emissions.

The ENZ model is a set of economic sub-models, where each sub-model represents a specific fossil sector (e.g. transport). Each sub-model aligns with standard economic theory, where the sub-model aims to identify the least cost means of meeting demand for a service, given the underlying parameters (e.g. input and technology costs, emissions prices, population). Some of the sub-models are technologically detailed, while others are less well developed, as there are information gaps for some sectors. When the ENZ model is incorporated with LURNZ model outputs, it allows the modelling to project emissions across the 'whole of New Zealand' and the emissions price paths required to meet an emissions reduction target.

Linkages between the LURNZ and ENZ models and the specific sectors that each model covers are incorporated by the outputs from one sector feeding into the inputs of another sector, both within and between the two models. For example, the outputs of the LURNZ model for dairy production are incorporated as inputs into the ENZ sub-model that captures the industrial process heat sector. This, in turn, results in further outputs being incorporated as inputs into the sub-model that captures the electricity generation and gas production sectors.

The approach of linking the LURNZ and ENZ models does have limitations, including that the linking process between the models does not capture all of the dynamic relationships across sectors.

The LURNZ and ENZ models are the same models used to provide insights in the 2018 *Low-emissions economy* report by the Productivity Commission. However, since the application of the ENZ model for the Productivity Commission, a number of improvements have been made to it. For example, the ENZ model applied for this report introduced a marginal abatement cost curve for geothermal emissions, and also modelled the development and depletion of New Zealand's gas reserves and gas prices.

Another notable difference between the two modelling efforts is the extension of the modelling time horizon out to 2075. To support modelling computation, the functional form of the emissions price path, reflecting the change in the emissions price over time, was amended in this modelling effort.

In the Productivity Commission report, the emissions price path was assumed after 2030 to increase at a constant rate out to 2050. In this modelling, an S-shaped or sigmoidal functional form was chosen to represent the emissions price path, so that emissions prices increased after 2030, but tapered off beyond 2050.

A final difference between the modelling efforts was that the linking process of modelling output from the LURNZ model to the ENZ model was improved to enable a better estimation of the emissions price required to meet a particular emissions reduction target. The specific detail of this improved linking process is as follows:

- For a given shape of emissions price paths over time (e.g. logarithmic, sigmoidal), the LURNZ model runs four or five different emissions price paths.
- The outputs from these model runs in the LURNZ model for the different emissions price paths are then fed into the ENZ model.
- An interpolation/extrapolation function is applied to the LURNZ model output within the ENZ model to project outcomes in the land-based sectors for emissions price paths different to those actually applied in the LURNZ model.
- The ENZ model then determines the emissions prices required to meet a given emissions reduction target.

Modelling assumptions

The modelling assumptions used to describe how key factors change over time, including the rates and types of technological change are indicated in Table A2.1. However, the assumptions regarding technological change were conservative ones. For example, the modelling assumed that there would be no technological breakthrough (e.g. methane vaccine) discovered for reducing biological emissions, but there would be an ongoing improvement in the efficiency of emissions per unit of agricultural product produced in line with historical trends.

Table A2.1. Modelling assumptions applied in the LURNZ and ENZ models.

Parameter	Modelling assumption
Policy instrument	
Emissions pricing coverage	Coverage of emissions pricing was assumed to be all emitting sectors, including agriculture.
Free allocation	From 2019–2020, allocation was assumed to be consistent with current NZ ETS. From 2020, fast withdrawal of free allocation assistance across all fossil sectors occurs, with withdrawal at 3 percentage points from 2020 to 2030, and 5 percentage points thereafter. Agriculture was assumed to receive 95% free allocation initially, with a 5 percentage point phase-out rate from 2020.
Agriculture and forestry	
Type of forest	Reforestation was assumed to be 66% plantation forests and 33% native forests.
Plantation forest sequestration	Plantation forest sequestration was assumed, as an annual rate, to be 31.8 tonnes of carbon dioxide equivalent per hectare. Payments for sequestration to 21 years after planting was assumed based on carbon look-up table information.[1]
Native forest sequestration	Native forest sequestration was assumed, as an average annual rate, to be 6.5 tonnes of carbon dioxide equivalent per hectare. Note that the sequestration rate of native forests is significantly lower than that of plantation forests. However, their effect is more enduring; removals associated with native reforestation continue throughout the modelling period, rather than stopping 21 years after plantings as for plantation forests.
Forestry emissions accounting	Averaging approach for plantation forest was assumed, with new forests credit up to 21 years after planting. No credit/debit was assumed after that if land was replanted.
Agriculture emissions intensity	Continuous improvement in the efficiency of emissions per unit of product produced with dairy and sheep and beef intensity in line with historical improvements.
Agricultural and forestry commodity prices	Commodity price forecasts were based on the Situation and Outlook for Primary Industries data.[2] Prices held constant beyond 2021, the last projection year of the outlook.

[1] Te Uru Rākau (Forestry New Zealand), 2018c.

[2] Ministry for Primary Industries, 2017b.

Parameter	Modelling assumption
Horticultural area	Horticulture land use does not respond endogenously in the LURNZ model, as the data available for this sector remains limited. However, the model does spatially allocate horticulture to suitable land based on geophysical and other characteristics. Hence, it was assumed that a linear increase in horticultural land with the implementation of emissions pricing occurs to approximately one million hectares by 2050 and a further linear increase to approximately 1.3 million hectares by 2075. These rates of horticultural expansion are higher than observed in historical trends, but they are considered feasible by horticultural experts.
Horticultural emissions	Horticultural emissions were assumed to be one tonne of carbon dioxide equivalent per hectare. This is close to mean emissions per hectare from kiwifruit and cropping, and is based on horticultural emissions factors provided by New Zealand Agricultural Greenhouse Gas Research Centre.
Dairy area	It was assumed that no new dairy conversions would be allowed from 2025, to approximate the impact of regional councils implementing freshwater quality limits in their regions. This assumption aligns with the Freshwater National Policy Statement, which directs regional councils to set objectives for the state of freshwater bodies and to set limits on resource use to meet these objectives.
Scrub	Scrubland was assumed to be suitable for reforestation.
Population and urban growth	
Population growth	Rate of population growth was assumed to be one per cent per year.
Urban area	Urban area was assumed to be constant over time. Urban area is less than one per cent of total land use in New Zealand.
Energy and transport	
Rate of electric vehicle battery cost reductions	Costs decline at 6% per year.
Extent of mode-shifting to public transport/vehicle sharing/active transport	50% increase over 30 years in the proportion of trips by public transport and active transport (e.g. cycling, walking), and 20% increase in proportion of vehicle sharing.
Rate of renewable technology cost improvement	Annual cost improvement for wind, solar and geothermal is 1.25%, 2.5% and 0.25%, respectively.
Rate of residential and commercial energy efficiency improvement	Energy efficiency improvements are disaggregated across the uses for which gas is employed and consumed. The assumed rate of improvement is 0.1% per year for all use except residential space heating, which is assumed to be 0.25% per year.
International unit prices	
International unit prices	An international price for emissions units was modelled that reached $37 per tonne of carbon dioxide equivalent in 2030 and then rose to $150 per tonne of carbon dioxide equivalent by 2075. This price reflects the lower end of estimated prices to achieve less than two degrees Celsius of warming, in keeping with goals set out in the Paris Agreement.

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