Scientific aspects of New Zealand's 2050 emission targets

A note on scientific and technical issues related to the Zero Carbon Bill

Andy Reisinger, Sinead Leahy
New Zealand Agricultural Greenhouse Gas Research Centre, Palmerston North

This note seeks to clarify the scientific basis and climate outcomes of emission reduction targets for New Zealand proposed in the Zero Carbon Bill and of alternative targets for methane emissions.

The note evaluates climate outcomes of the emission targets in the Zero Carbon Bill and clarifies key findings and assumptions in the recent IPCC report on global warming of 1.5°C referred to in the Bill. It also seeks to clarify assumptions that underpin alternative emission targets for methane that have been proposed.

We hope that the information in this note helps decision-makers separate the roles of climate science and of value judgements in setting emission targets for New Zealand. Both play necessary but distinct roles.

Contents

June 2019

DISCLAIMER: While all reasonable endeavour has been made to ensure the accuracy of the information contained in this note, NZAGRC expressly disclaims any and all liabilities contingent or otherwise that may arise from the use of the information. The views expressed in this report are those of the individual authors and do not necessarily represent the views of NZAGRC or its partner organisations.

The work in this note builds on earlier work commissioned by the Parliamentary Commissioner for the Environment (see Reisinger, 2018) and the authors are grateful for the stimulus that this initial work provided. Funding for this note has been provided by the NZAGRC.

This note was peer reviewed by Dr Joeri Rogelj, coordinating lead author for Chapter 2, "Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development", in the recent Special Report on Global Warming of 1.5°C by the Intergovernmental Panel on Climate Change. However, responsibility for any judgements, omissions or errors remaining in this note rests solely with its authors.

Executive summary

- New Zealand's total gross greenhouse gas emissions to date (fossil carbon dioxide, nitrous oxide, and biogenic methane) are estimated to have contributed a little over 0.0028°C to the observed global warming of about 1°C above pre-industrial levels. While small in absolute terms, New Zealand's share in global warming to date is more than 4 times greater than its share of the global population and about 1.5 times greater than its share of the global land area.
- New Zealand's biogenic methane emissions currently make a bigger estimated contribution to global warming than cumulative emissions of fossil carbon dioxide and nitrous oxide combined. If gross emissions of those three gases continued at current rates, biogenic methane would remain New Zealand's largest single contributor to global warming for the next six decades despite its relatively short lifetime in the atmosphere compared to carbon dioxide and nitrous oxide.
- Reducing net emissions of long-lived greenhouse gases to or below zero as quickly as possible is essential to support the temperature goal of the Paris Agreement. The net-zero target proposed in the Zero Carbon Bill could be achieved in different ways, such as reducing all gases individually to zero, or offsetting nitrous oxide emissions with additional carbon dioxide removals. The climate outcomes under different approaches would be very similar if the Global Warming Potential is used to compare nitrous oxide and carbon dioxide emissions.
- Reducing New Zealand's biogenic methane emissions creates unambiguous and substantial benefits to the climate, in addition to the benefits of reducing long-lived gases. However, methane reductions should occur only *in addition, not as a substitute* to reducing emissions of long-lived greenhouse gases to net zero. Otherwise the cumulative warming from long-lived gases could eventually outweigh any benefit from methane reductions. The Zero Carbon Bill's provision of a separate target for biogenic methane emission helps avoid perverse outcomes that could occur from trade-offs between those gases under an all-gases target.
- Climate science cannot tell us how much New Zealand should reduce its emissions: the lower all emissions including methane can go, the better for the climate. The question for agriculture is what methane emission reductions are possible while still helping to sustain and support New Zealand's economy and maintaining viable and vibrant rural communities and businesses.
- The IPCC identified a range of 24-47% global agricultural methane emission reductions by 2050, relative to 2010, in emission pathways that keep warming to 1.5°C. This wide range reflects different scenarios, strategic choices, and economic assumptions to achieve the temperature limit at the least cost globally. While this range can serve as reference point, it does not in itself prescribe a specific target for methane emissions reduction by any individual country. A national target necessarily depends on national value judgements around what is an appropriate contribution by New Zealand and the economic cost of reducing emissions in New Zealand.
- Some stakeholders have advocated an alternative methane target, with reductions set such that future methane emissions do not create additional warming above current levels. For this goal to be met, New Zealand's biogenic methane would need to be reduced by 10-22% below current levels by 2050, depending on future changes in global methane emissions. Whether this approach is more equitable depends on whether equity is defined as causing the same additional warming or as making the same effort to reduce future emissions. The two are not the same. For short-lived gases like methane, a target based on 'not causing additional warming' amounts to a grand-parenting approach, i.e. an entitlement to continue to emit methane in future at a level that is determined solely by past emissions regardless of abatement potential or cost. Like all grand-parenting approaches, this raises equity issues that cannot be resolved by climate science.

1. Purpose

The Government recently introduced the Climate Change Response (Zero Carbon) Amendment Bill, with the purpose "*to provide a framework by which New Zealand can develop and implement clear and stable climate change policies that contribute to the global effort under the Paris Agreement to limit the global average temperature increase to 1.5° Celsius above pre-industrial levels*".

The purpose of this technical note is twofold:

1) to provide a scientific evaluation of the climate implications of the emission targets contained in the Zero Carbon Bill, and
2) to provide additional explanation of the findings from the recent Special Report by the Intergovernmental Panel on Climate Change (IPCC, 2018) on global emission pathways that would limit warming to 1.5°C relative to pre-industrial levels, with a focus on agriculture.

The note also considers the scientific basis and assumptions implicit in other targets that have been proposed for New Zealand's methane emissions.

2. Introduction and Context

The Zero Carbon Bill includes new greenhouse gas emission reduction targets for the year 2050:

- To reduce gross emissions of biogenic methane to 24% to 47% below 2017 levels by 2050, with an interim requirement to reduce emissions to 10% below 2017 levels by 2030, and
- To reduce net emissions of all other greenhouse gases to zero by 2050.

In setting those targets, the Zero Carbon Bill refers explicitly to the findings in the recent IPCC Special Report on Global Warming of 1.5° (IPCC, 2018).

Agreeing on any national policy framework to achieve long-term climate change outcomes, and setting emission reduction targets, inevitably will require balancing a complex set of objectives and value judgements. However, natural and social science can help inform such judgements by quantifying the climate outcomes from different targets and clarifying underlying assumptions by:

- quantifying the climate outcomes from the Zero Carbon Bill's targets
- clarifying the methodology and assumptions in the recent IPCC Special Report on Global Warming of 1.5° (IPCC, 2018), which the Government has used to set the indicative emission reduction target range for biogenic methane
- clarifying the implicit or explicit assumptions necessary to move from emission reduction ranges in global emission scenarios to national targets, and the assumptions inherent in alternative emission targets that have been proposed especially for New Zealand's agricultural methane emissions.

The NZAGRC has not been involved in the setting of targets in this Bill and the authors of this note make no judgement as to whether the targets are appropriate.

3. Climate consequences of New Zealand's 2050 emission targets

3.1 New Zealand's contribution to climate change from emissions to date

The Paris Agreement, which the Zero Carbon Bill seeks to support, aims to limit the increase in global average temperatures to "*well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change*".

New Zealand's current total contribution to global warming is dominated by historical carbon dioxide emissions and removals from land-use change (see Figure 1). A significant fraction of these emissions occurred during the first few centuries of human settlement, well before the global industrial revolution (PCE, 2019).

Given the uncertainties and distant historical legacy relating to emissions from land-use change, we focus in the remainder of this note only on the warming caused by New Zealand's gross emissions from fossil carbon dioxide, biogenic methane, and nitrous oxide. These emissions started largely only after European settlement and accelerated during the 20th and early 21st century (see e.g. Ausseil *et al.*, 2013). The biggest contribution to global warming from New Zealand's gross emissions of these gases currently comes from biogenic methane (mainly from ruminant livestock but also landfill waste), followed by fossil carbon dioxide and nitrous oxide. [1]

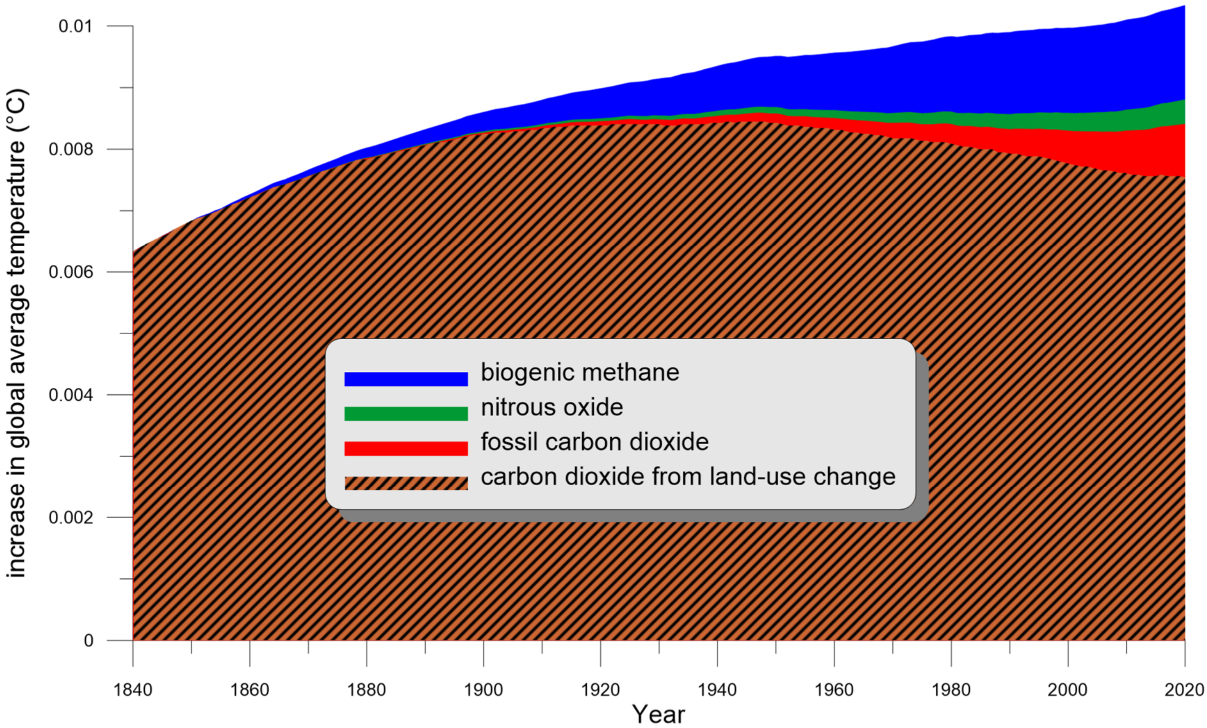

Figure 1. Calculated total contribution to global average temperature change from New Zealand's emissions to date. Emissions and associated warming of carbon dioxide from historical land-use change, fossil carbon dioxide, nitrous oxide, and biogenic methane from livestock are based on (PCE, 2019). Emissions of biogenic methane from waste were estimated using the national greenhouse gas emissions inventory and extrapolated back to 1840, and were added to methane emissions from livestock before calculating the resulting warming using the methodology in Reisinger (2018).

[1] We have not included in our calculations for this note any emissions of fossil methane or synthetic greenhouse gases (mainly hydrofluorocarbons). These gases currently contribute about 3.2% of New Zealand's total gross emissions. While clearly not irrelevant, their inclusion would not have fundamentally changed the broad results in this note.

The total amount of warming in the year 2019 estimated to have been caused by New Zealand's gross emissions of fossil carbon dioxide, nitrous oxide and biogenic methane to date is just under 0.0028°C. Global temperatures increased during the same period by about 1°C; this increase broadly matches the warming expected as a result of human activities over this period (IPCC 2018).

New Zealand's share in the observed global warming is small (about 0.28%), but more than 4 times greater than its share of the global population (about 0.06%) and about 1.5 times greater than its share of the global land area (about 0.18%).

Given the long lifetime of carbon dioxide and nitrous oxide in the atmosphere, past and current emissions of these gases will contribute to keeping Earth at elevated temperatures throughout the next few centuries and, in the case of carbon dioxide, millennia. Future emissions of these long-lived gases will add further to the warming caused already until those emissions are reduced to net zero.

By contrast, the warming caused by past and current biogenic methane emissions will largely disappear within the next few decades, given the shorter lifetime of methane in the atmosphere. The contribution from biogenic methane to future global warming therefore depends almost entirely on future emissions of this gas.

3.2 Achieving "net zero" emissions of long-lived greenhouse gases

One of the two emission targets of the Zero Carbon Bill is to achieve "net zero" emissions of all gases other than biogenic methane by 2050. The long-lived gases carbon dioxide and nitrous oxide make up the bulk of these emissions (see footnote 1).

The Bill's provision for a "net zero" target for these gases leaves it open whether this goal is reached by reducing emissions of each gas to zero individually, or whether some emissions that are difficult to avoid entirely would be offset by additional carbon removals.

Purely from a climate perspective, it makes no difference whether some on-going fossil emissions are offset by active removal of carbon dioxide from the atmosphere (via afforestation or any other means). The consequences for the climate would be virtually identical.

However, as noted e.g. by the Parliamentary Commissioner for the Environment (PCE, 2019), offsetting large quantities of fossil carbon dioxide emissions through large-scale afforestation may have important and unintended consequences for rural communities and may present risks to the future climate given the vulnerability of forests to fire, pests and diseases and hence impermanence of carbon removals via afforestation. If fossil carbon dioxide emissions continue at significant rates and carbon removal is undertaken only by afforestation, rather than more technological approaches such as bioenergy combined with carbon capture and storage or direct air capture and storage, this would also raise serious concerns about the availability of land in the longer term.

These concerns are relevant and important for any political decisions to manage the use of carbon offsets, but they do not change the results presented and discussed in this note, which focuses on scientific and technical aspects of emission targets, not how to best meet net emission targets from a broader social, economic and risk management perspective.

Another question is whether on-going emissions of nitrous oxide can be effectively offset by additional carbon dioxide removals. This is highly relevant since it will be virtually impossible for nitrous oxide emissions to be reduced to zero. Even the most efficient agricultural production systems result in some nitrous oxide being lost to the atmosphere.

Figure 2 illustrates different scenarios in which the goal of "net zero" emissions by 2050 could be achieved for nitrous oxide and carbon dioxide emissions. One hypothetical scenario would be that emissions of both gases are reduced to zero. Another scenario would be that nitrous oxide emissions remain at current levels and are offset entirely by additional carbon dioxide removals. A third, probably most likely scenario, would be some combination of these two.

The actual warming caused by these different scenarios is very similar, although the relative contribution from nitrous oxide and carbon dioxide differs. Total warming would be slightly less if nitrous oxide emissions could be reduced to zero, rather than offset by carbon dioxide removals. However, the difference in outcomes is small (about 3% of the total warming caused by both gases together in 2050, and about 6% by 2100). If this balance between nitrous oxide emissions and carbon dioxide removals were retained post-2050 through to the 22nd century, the difference would not increase further, and would in fact shrink and reverse again during the 23rd century.

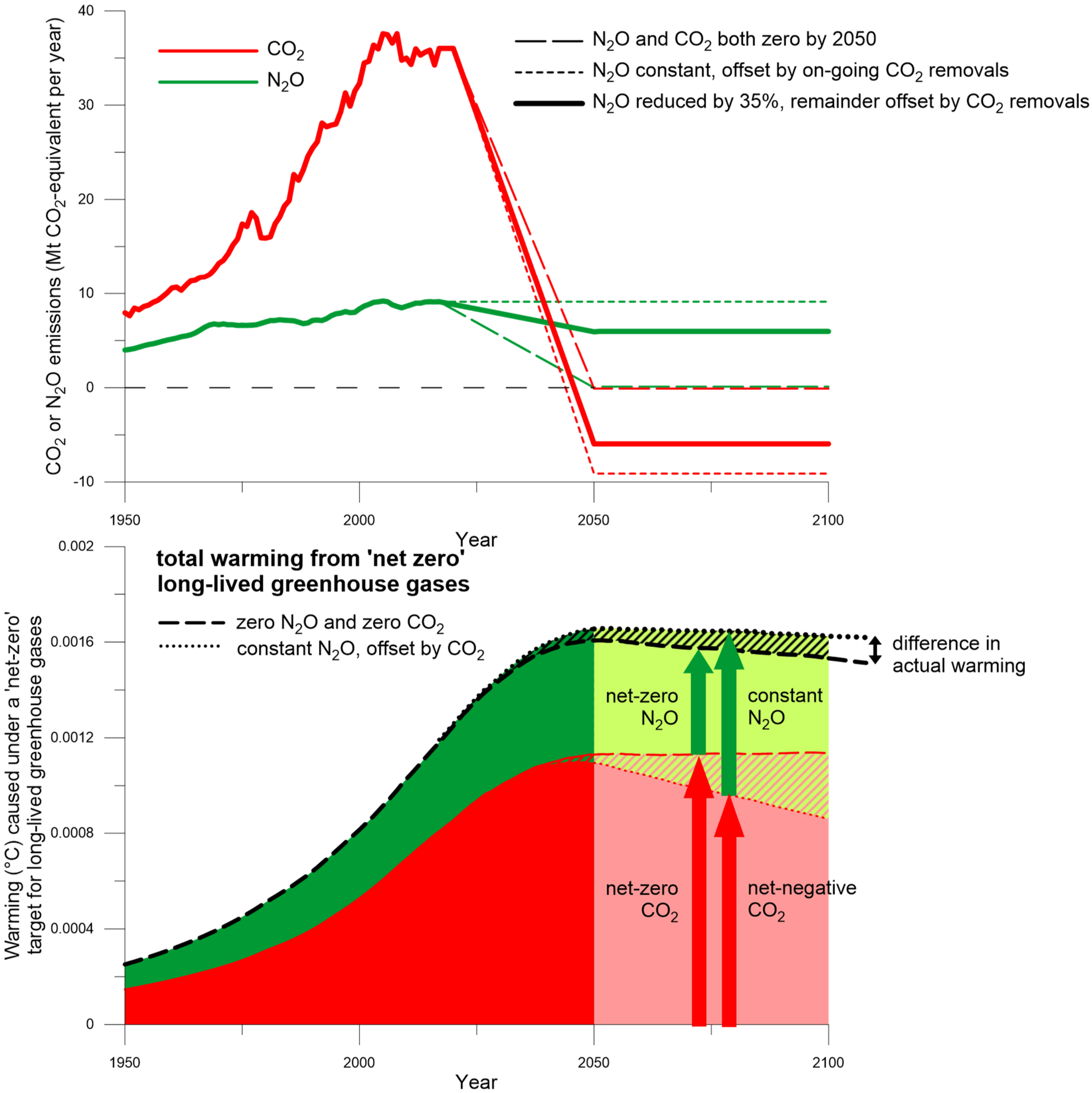

Figure 2. Illustrative scenarios of reaching net zero emissions of fossil carbon dioxide (red) and nitrous oxide (green) by 2050. All scenarios satisfy the goal of “net zero” emissions by 2050. The upper panel shows emissions, the lower temperature change. Dashed lines are for a scenario where both nitrous oxide and carbon dioxide emissions reach zero by 2050; dotted lines are for a scenario where nitrous oxide emissions remain constant and are offset by on-going carbon dioxide removals. Solid lines represent an intermediate scenario where nitrous oxide emissions are reduced by 35% and the remainder offset by carbon removals. Vertical arrows illustrate the contributions from nitrous oxide and carbon dioxide to the total warming from long-lived gases under the different scenarios. Emissions are assumed to remain constant beyond 2050 in each scenario. Note that this assumption is made only for illustrative purposes, as all emissions scenarios consistent with a 1.5°C goal require further global emission reductions (and additional carbon removals) beyond 2050.

These results indicate that from a climate perspective, there is only a minor difference whether the "net zero" target is achieved by reducing nitrous oxide and carbon dioxide both to zero, or by net removals of carbon dioxide compensating for on-going nitrous oxide emissions. In other words, actually achieving "net zero" emissions of these two gases is much more important for the climate than how the net-zero goal is achieved.

The relatively similar outcomes are to be expected, given that nitrous oxide has a lifetime in the atmosphere of more than 100 years and hence behaves similarly (though not identically) to carbon dioxide over this time frame. Using GWP_{100} to translate nitrous oxide into "CO_2 equivalent" emissions therefore appears defensible at least over the time frame of a few centuries.

3.3 Climate outcomes from the 2050 emission reduction targets

Figure 3 shows the emissions and resulting warming over the 21st century from past and future emissions of fossil carbon dioxide, nitrous oxide, and biogenic methane individually if emissions follow the targets proposed in the Zero Carbon Bill.[2]

In the absence of longer-term targets, we assume emissions to remain constant at the levels proposed in the Bill from 2050 onwards, but note that global pathways that limit warming to 1.5°C or well below 2°C have emissions of all gases falling further after 2050 (see Section 4). To illustrate the climate benefits of the emission reductions proposed in the Bill, we also show outcomes if emissions of all gases remained constant from 2017 onwards.

Figure 3 demonstrates that biogenic methane currently makes New Zealand's biggest contribution to global warming and constant emissions would result in an increasing contribution. Reducing emissions in line with the target range proposed in the Zero Carbon Bill would roughly stabilise the warming from biogenic methane at current levels (for a 24% reduction by 2050) or reduce it below current levels (for a 47% reduction by 2050).

New Zealand's fossil carbon dioxide emissions contribute less warming currently, but their contribution is increasing more rapidly than the warming from methane, given the cumulative warming effect from this long-lived gas. If carbon dioxide emissions remained constant at current levels, their warming would eventually exceed the warming due to New Zealand's biogenic methane emissions by about 2080 and continue rising thereafter.

New Zealand's nitrous oxide emissions make the smallest contribution to warming of these three gases, but the contribution is rising. Warming from nitrous oxide will continue to rise even if its emissions are reduced substantially (e.g. the contribution to warming increases even if nitrous oxide emissions were reduced by 35% by 2050, which would mirror the mid-range of the Zero Carbon Bill's emission reduction target for biogenic methane).

If nitrous oxide emissions were reduced to zero, their contribution to warming would decline slowly over the coming centuries. However, reducing emissions anywhere close to zero is not practically possible (even with new mitigation technologies under development) while New Zealand retains any agricultural activity. Achieving the "net zero" goal will inevitably have to rely on some amount of additional and sustained carbon dioxide removals to compensate for nitrous oxide emissions that cannot be avoided, but how much nitrous oxide might reduce within this goal is an open question.

---

[2] The warming shown and discussed in this Section has been calculated on the assumption that the world as a whole will reduce emissions by 2050 consistent with the goal of the Paris Agreement to limit warming to well below 2°C. Lesser global action would result in greater global warming but would slightly reduce the warming caused by New Zealand's emissions (see Section 5.1). This would not fundamentally change the overall picture in terms of the contributions of different gases emitted by New Zealand, but it can change outcomes at the margin. Appendix I presents Figure 3 and Figure 4 calculated for a scenario where the world fails to meet the temperature goal of the Paris Agreement.

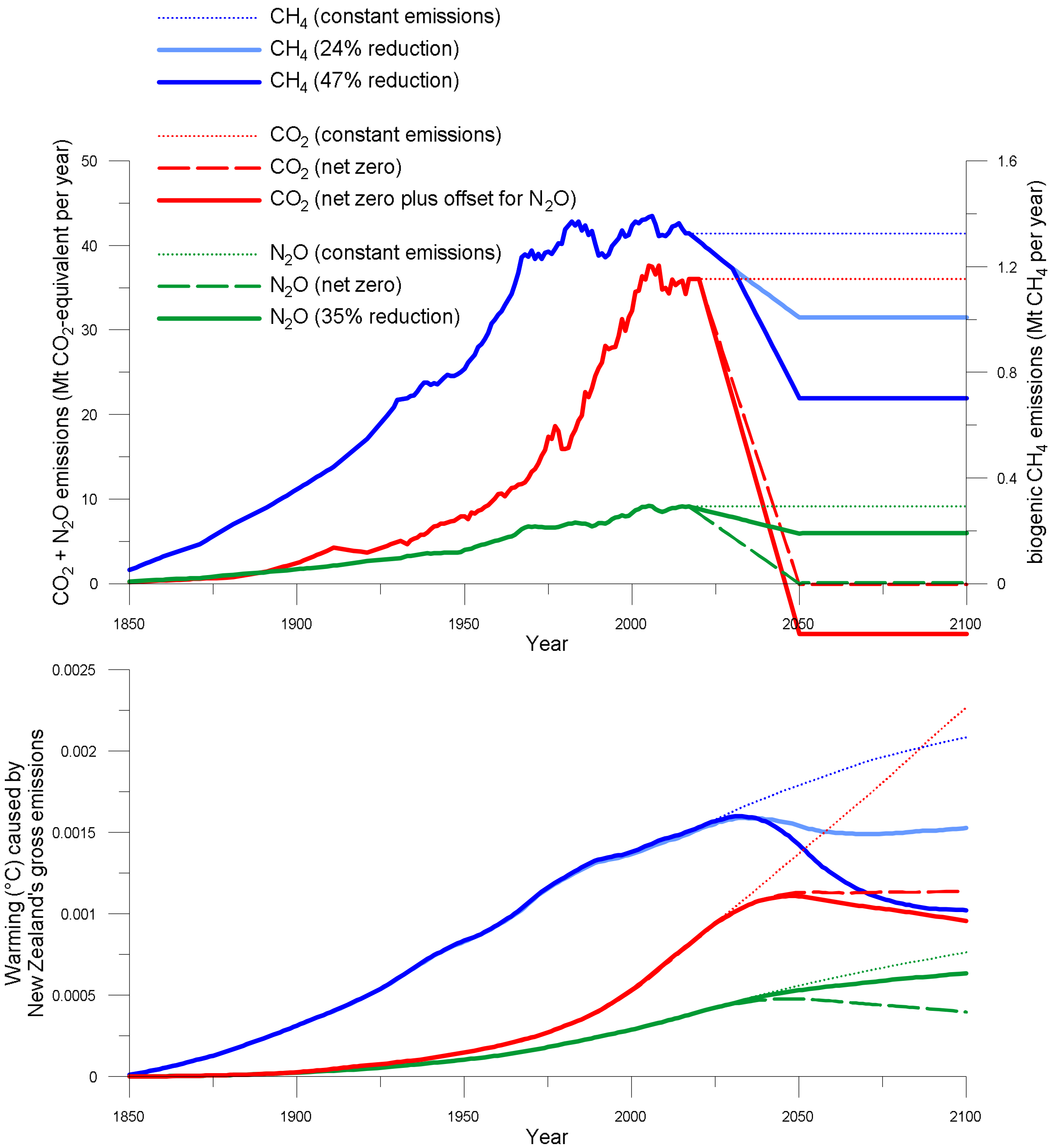

Figure 3. New Zealand emissions (top panel) and their contribution to global warming (bottom panel) from individual greenhouse gases for emissions consistent with the Zero Carbon Bill. For nitrous oxide, we assume a 35% reduction by 2050, with remaining emissions offset by additional carbon removals, but also show results if emissions were reduced to zero. Dashed lines show emissions and warming if emissions were held constant from 2017 onwards.

Figure 3 illustrates that there are clear and substantial benefits to the climate from reducing methane emissions. Compared to constant emissions, reducing New Zealand's biogenic methane emissions by 47% by 2050 (the upper end of the range proposed in the Zero Carbon Bill), and keeping emissions constant thereafter, would avoid almost the same amount of warming in 2100 as reducing New Zealand's fossil carbon dioxide emissions to zero by 2050.

Figure 4 shows the total contribution to warming from New Zealand's gross emissions of fossil carbon dioxide, nitrous oxide, and biogenic methane for the targets set out in the Zero Carbon Bill.

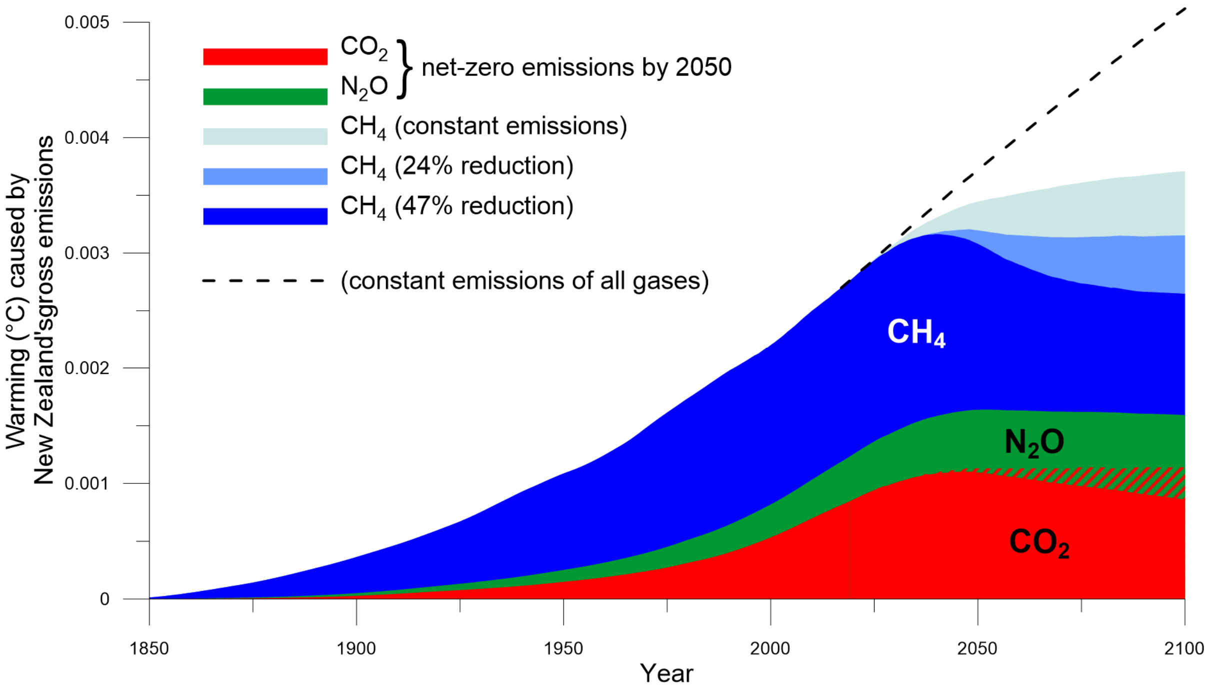

Figure 4. Combined contribution to global average temperature change from New Zealand's gross emissions of fossil carbon dioxide, nitrous oxide, and biogenic methane. Shaded areas represent the warming for the emission targets proposed in the Bill, with constant emissions after 2050. The dashed line shows the warming from constant emissions at 2017 levels. Different ways of reaching net-zero carbon dioxide and nitrous oxide emissions would not affect the overall warming but alter the relative contributions of those gases (see Section 3.2) as indicated by the red-green hatched area.

Reducing fossil carbon dioxide and nitrous oxide emissions to net zero by 2050 would result in additional warming from those gases combined above current levels until that time. After 2050, their contribution to warming would stabilise and decline very slowly if emissions remain constant after 2050 levels. However, if biogenic methane emissions remain at current levels, New Zealand's overall contribution to climate change would still continue increase well beyond 2050.

If, in addition, biogenic methane emissions were reduced by 10% below 2017 levels by 2030, and by 24% by 2050, this would result in additional warming from all emissions until 2050. If emissions of all gases then continue at the same level after 2050, New Zealand's contribution to global warming would remain at approximately the same level for the second half of the 21st century.

If biogenic methane were reduced by 47% below 2017 levels by 2050, this would see the total warming caused by New Zealand peak around 2040 and decline thereafter. If emissions of all gases then continue unchanged, New Zealand's contribution to global warming by the end of the 21st century would be slightly below the warming caused today.

In combination, these results illustrate that there are clear benefits, in terms of avoided climate change, from reducing net emissions of fossil carbon dioxide and nitrous oxide to zero, as well as from reducing biogenic methane emissions as much as possible. However, this should not be used to pick one target over the other: the climate benefits of reducing biogenic methane are effective only as *in addition to* reducing emissions of long-lived greenhouse gases to net zero, since any continued emissions of long-lived gases would continue to add to warming indefinitely. The dual target contained in the Zero Carbon Bill is consistent with this basic scientific perspective.

Climate science on its own cannot tell us how quickly we should reduce long-lived gases to net zero, or how low we should reduce biogenic methane emissions. The earlier net emissions of long-lived gases are reduced to zero, and the lower biogenic methane emissions can be reduced, the less New Zealand will contribute to future climate change. How fast and how deep New Zealand can reduce its emissions is a question of economics, social and distributional impacts, not of climate science.

4. Findings from the IPCC Special Report on 1.5°C

4.1 High-level summary

The Zero Carbon Bill explicitly refers to the findings from the IPCC's Special Report on Global Warming of 1.5° (IPCC, 2018). This report provides a comprehensive assessment of the scientific literature on how the world could limit global warming to 1.5°C above pre-industrial levels, as this is part of the goal set out in the Paris Agreement. The report also assessed the impacts of this amount of warming and compared it to impacts if the world warms by 2°C or even more.

The IPCC found that to limit warming to 1.5°C, the world as a whole would need to reach net-zero emissions of carbon dioxide by about 2050, along with deep reductions in non-CO_2 emissions. Emissions reductions would need to continue beyond 2050, with net removals of carbon dioxide from the atmosphere at the global scale. Achieving these outcomes would require rapid and far-reaching transitions in energy, land, urban and industrial systems including transport and buildings.

Figure 5 illustrates graphically the scale and pace required for reductions in global carbon dioxide emissions, for a wide range of scenarios that would all limit the global temperature increase to 1.5°C with no or limited overshoot. The rate of emission reductions globally would have to be significantly greater than the historical rate of emissions increase.

The Figure also shows that the world as a whole will have to achieve net negative carbon dioxide emissions (i.e. carbon dioxide removals greater than gross emissions) from about 2050 onwards to remain within the 1.5°C temperature limit. This is in part to compensate for emissions of other long-lived greenhouse gases that cannot be reduced to zero, and in part to compensate for any overshoot of the temperature limit resulting from the failure to reduce emissions during the early 21st century.

Given this global perspective, a goal of net zero emissions for a long-lived gas like carbon dioxide can thus only be viewed as an intermediate milestone, not as end-point of low-emissions development.

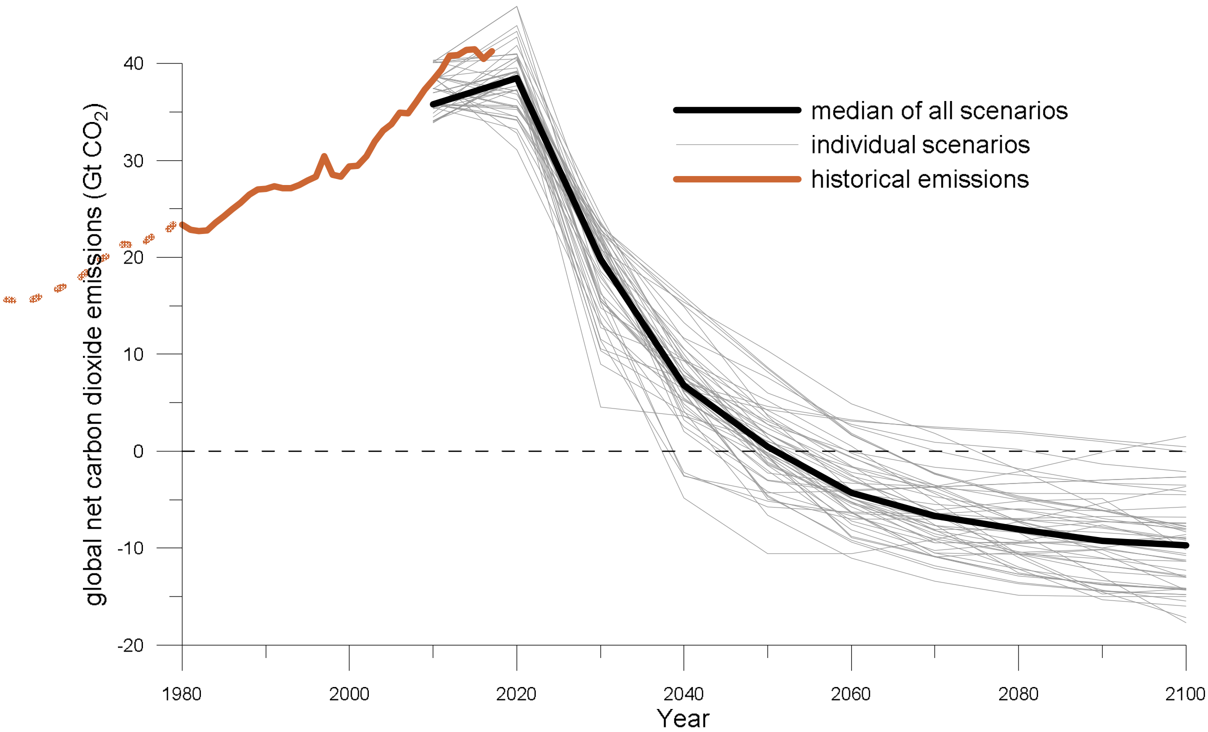

Figure 5. Global net carbon dioxide emission pathways that result in no or only limited overshoot of the 1.5°C temperature limit, taking into account the contribution from other greenhouse gases and aerosols. (Source: Huppmann, et al. (2018): *IAMC 1.5°C Scenario Explorer and Data hosted by IIASA.* Integrated Assessment Modelling Consortium & International Institute for Applied Systems Analysis, 2018. data.ene.iiasa.ac.at/iamc-1.5c-explorer).

4.2 Global agricultural emission pathways in scenarios that limit warming to 1.5°C

As part of its report, the IPCC compiled an extensive database of global emission pathways from the scientific literature that would limit the increase in average temperature to various levels.[3]

Out of 411 global scenarios, 74 would limit warming to well below 2°C (i.e. remain below 2° with greater than 66% probability), and 53 would limit warming to 1.5°C with no or limited overshoot. Here we summarise the biological greenhouse gas emissions from agriculture in these scenarios.

A key feature of the modelled global pathways is that they are all based on the objective of limiting the global temperature increase to a certain level, and to do so at the least global cost.

The models all recognise the different atmospheric behaviour of different greenhouse gases but differ in their assumptions about the availability and cost of different mitigation options. Consequently, they differ in the relative contributions from different sectors and technologies to greenhouse gas emissions and mitigation. Models also explored the consequences of additional constraints and assumptions about e.g. the deployment of nuclear power, renewables, bioenergy, global trends in dietary choices and calorie demand, and the consequences of delay or acceleration in climate policy in different sectors and world regions.

Figure 6 shows the modelled changes in global emissions of methane and nitrous oxide from agriculture, for scenarios that could be considered consistent with the Paris Agreement as they either limit warming to 1.5°C with no or limited overshoot, or to below 2°C with greater than 66% probability. Also shown are projected emissions in scenarios without any climate policy.

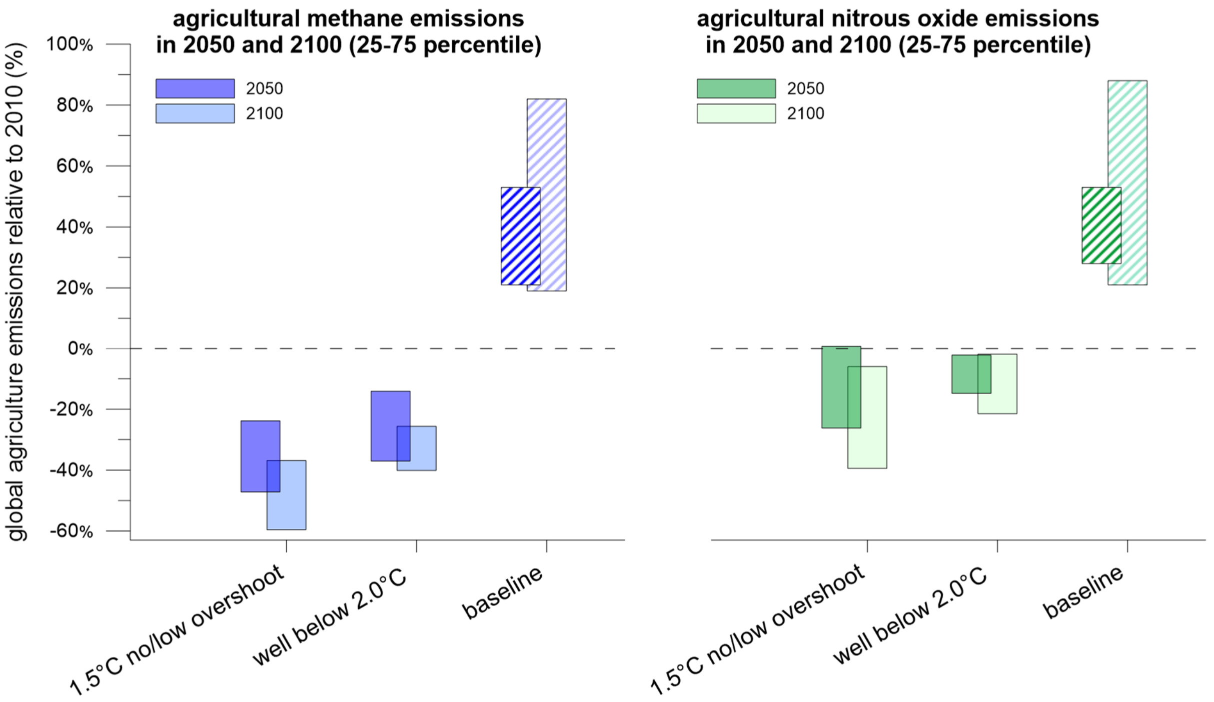

Figure 6. Changes in global emissions of methane (left) and nitrous oxide (right) from agriculture, forestry and other land-use (mainly agriculture) under scenarios that limit achieve global temperature outcomes consistent with the Paris Agreement. Hatched bands indicate projected emissions in baseline scenarios in the absence of climate policy in any sector.

[3] See: Huppmann, et al. (2018): *IAMC 1.5°C Scenario Explorer and Data hosted by IIASA.* Integrated Assessment Modelling Consortium & International Institute for Applied Systems Analysis, 2018. data.ene.iiasa.ac.at/iamc-1.5c-explorer. For more details, see Rogelj *et al.* (2018).

Emission are generally reduced even more by 2100 than by 2050, and emissions reductions are generally greater the lower the intended temperature limit. Emission reductions for nitrous oxide are generally less than for methane, reflecting the assumption in most models that there are fewer options to reduce nitrous oxide emissions from agriculture globally at a given cost than for methane.

For scenarios that limit global average temperature to 1.5°C with no or limited overshoot, the interquartile (25 to 75 percentile) range of scenarios has a reduction of methane emissions from agriculture by 24-47% in 2050 relative to 2010, with greater reductions of 37-60% by 2100.

By comparison, modelled changes in nitrous oxide emissions from agriculture in these same scenarios range from +1 to -26% by 2050, with greater reductions of 6-39% by 2100.

For context, methane emissions arising from the extraction and use of fossil fuels are reduced by 79-88% by 2050 relative to 2010, and carbon dioxide emissions from energy and industry are reduced by 82-99% by 2050 relative to 2010 (interquartile ranges). Reductions of agricultural emissions in these scenarios are thus significantly less stringent than for other sectors. This reflects an assumption common across most integrated assessment models that it is significantly more expensive and less feasible to make deep emission reductions in the agriculture sector than in most other sectors. None of these scenarios assume novel mitigation technologies for agriculture such as methane inhibitors or vaccines, or nitrification inhibitors for nitrous oxide.

Figure 7 shows in more detail the individual scenarios of global methane emissions from agriculture for pathways that limit the increase in global temperature to 1.5°C with no or limited overshoot, along with the median and interquartile range. Some scenarios reduce methane emissions by significantly more than 50% below 2010 levels by 2050, whereas others show virtually no reduction.

Scenarios that achieve the deepest emission reductions tend to assume not only changes in production systems but also changes in global dietary patterns as well as reduced food loss and waste and low population growth. While the assumptions in each individual scenario clearly are contestable, the range of emissions reductions across a diversity of models and scenarios with different assumptions is likely to be more robust than the results from any individual model.

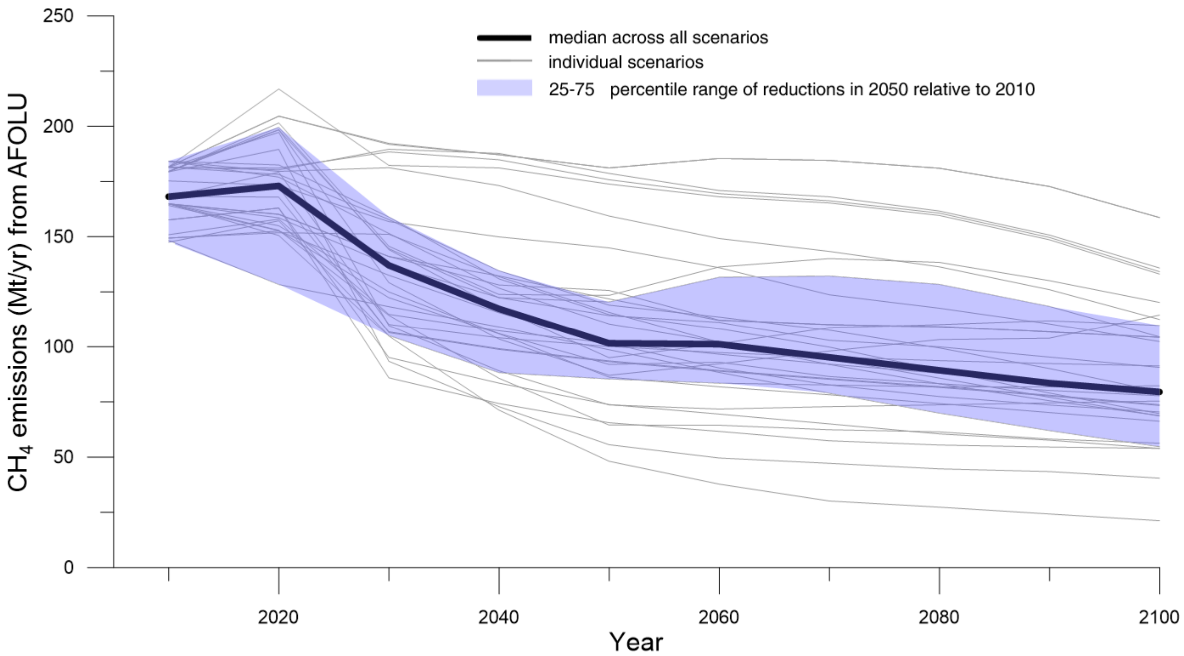

Figure 7. Individual scenarios and quartile ranges of global agricultural methane emissions in scenarios that limit the increase in global average temperature to 1.5°C with no or limited overshoot.

4.3 Interaction between carbon dioxide and methane in global scenarios

The IPCC report makes clear that globally, reducing carbon dioxide emissions to net zero by about 2050 is critical if the temperature increase is to be limited to 1.5°C. This is consistent with the fact that globally, carbon dioxide is the dominant driver of human-induced climate change and that there is a finite budget of carbon dioxide that can be emitted while remaining within this temperature limit. At current emission levels, the remaining global carbon budget of 570 to 770 Gt CO_2 for a 1.5°C limit will be depleted within 14-18 years, given current emissions of over 41 Gt CO_2 per year.

However, the above carbon budget assumes that emissions of other greenhouse gases and aerosols are reduced at the same time. Consequently, there is a clear interaction between the allowable global carbon budget and the emissions and contributions to global warming from other climate forcers (greenhouse gases other than CO_2, and aerosols such as black carbon). Within the range of scenarios assessed from the scientific literature, more ambitious action to reduce non-CO_2 emissions would increase the remaining allowable carbon budget consistent with the 1.5°C limit by about one third, whereas less ambitious action could decrease it by about one third.

In all modelled scenarios assessed by the IPCC that keep temperature to 1.5°C, methane emissions from all sources are reduced by *at least* 35% below current levels, but the median reduction across the range of different scenarios is 57%. Methane therefore contributes significantly less to global warming in 2050 in these scenarios than it contributes today.

If global methane emissions were reduced only as much as necessary to avoid *additional* warming above current levels from those emissions, this would drastically reduce the carbon budget compatible with 1.5°C. in that case, global carbon dioxide emissions would have to reach net zero more than 20 years earlier, i.e. before 2030, for the world to remain within the 1.5°C limit.

The balance between reductions of methane and carbon dioxide in the different scenarios reflects the mitigation costs for the different gases assumed in different global economic models along with the different impacts of these gases on global temperature. If a model assumes relatively low mitigation costs for methane, it will reduce those emissions more and allow a longer time to bring carbon dioxide emissions to zero. Vice versa, if a model assumes a high cost of reducing methane emissions, it will reduce those emissions less but in turn will have to reduce carbon dioxide emissions to zero earlier. Economic models balance those emissions reductions such that the total global cost across all sectors is minimised for a given temperature outcome.

4.4 Applicability of global emission reduction ranges to New Zealand

The New Zealand Zero Carbon Bill proposes a 2050 reduction target range for biogenic methane (agriculture and waste) of 24-47% below 2017 levels. This range corresponds to the interquartile range of global agricultural methane emission reductions in 1.5°C IPCC scenarios, but the IPCC range is for methane from agriculture only and reductions are relative to 2010 emissions not 2017. [4]

Apart from those differences, a key question is to what extent the global emission reduction ranges assessed by the IPCC can give guidance for national targets.

The IPCC made clear that the global scenarios do not constitute requirements at national level, i.e. emission targets for individual countries can obviously deviate from a global target. However, national targets cannot all deviate from the global target in the same direction since otherwise the

[4] Methane from waste comprises about 12% of New Zealand's total biogenic methane emissions. Methane emissions from waste declined by about 10% between 2010 and 2017, whereas methane emissions from agriculture increased by a little over 2% over the same period, with a total change of biogenic emissions of less than 1%.

global target would not be achieved. If some countries reduce their emissions by less than the global target, others will have to reduce their emissions by more if the global target is to be met.

Keeping in mind that the IPCC scenarios meet the global temperature limit at least global cost, using global scenarios as reference for New Zealand's domestic targets implies two key assumptions:

1) New Zealand's national overall emission reductions should be similar to global emissions reductions in pathways that limit warming to 1.5°C

2) The relative costs of abatement of the different gases and sectors in New Zealand are approximately the same as in the rest of the world.

Assumption 1 relies on ethical judgements whether New Zealand's overall emission reductions should mirror the necessary global average reductions, or whether New Zealand as a developed and comparatively wealthy country should undertake greater reductions than the global average. The latter would recognise that less developed countries will find it more difficult to achieve the same rate of emission reductions. This is a question of how New Zealand interprets and gives effect to the principle of "common but differentiated responsibilities" contained in the Paris Agreement.

The Zero Carbon Bill's target of reaching net-zero emissions of carbon dioxide and nitrous oxide clearly constitutes a more ambitious target than in pathways consistent with 1.5°C, as those pathways reduce only carbon dioxide emissions to net-zero by 2050 but achieve only limited reductions of nitrous oxide. By contrast, the Bill's target to reduce biogenic methane by 24-47% is slightly less ambitious than global scenarios, because reductions of methane from waste are generally assumed to be greater than reductions from agriculture due to lower abatement cost.[5]

Another important question is whether New Zealand actions should be guided by what the world as a whole *should* achieve to meet the objectives of the Paris Agreement or by the *actual* commitments and progress made by other countries. The collective mitigation commitments expressed by countries in their Nationally Determined Contributions under the Paris Agreement are currently insufficiently ambitious to limit warming to well below 2°C, let alone 1.5°C.

Answering these questions has little to do with the nature of methane as a short-lived gas but relies on ethical judgements and norms as well as geopolitical considerations.

Assumption 2 depends on whether efforts by New Zealand to reduce its biogenic methane emissions by 24-47% would have similar costs, benefits and broader social implications across New Zealand as reaching net zero emissions of carbon dioxide and nitrous oxide.

Again, answering this question is not contingent on methane being a short-lived gas but depends on economics, social impacts, and assumptions about future technologies and global markets.

Information about the actual cost of abatement remains limited given the absence of abatement incentives to date and hence limited practical experience of farmers incorporating greenhouse gas emissions into business decisions. Any emission target or target range for 2050 therefore can only be considered as an indicative starting point that must be subject to revision based on advances in mitigation technologies, possible changes in international markets and consumer demand, and actual responses of farmers to abatement incentives and the implications for rural communities.

[5] No detailed information about emissions reductions from waste are available from the publicly available IPCC database, but integrated assessment models generally assume methane emissions from waste (especially landfills) to be less costly to abate than methane emissions from agriculture (see Harmsen *et al.* (2019)). In the absence of New Zealand-specific information, we can only assume that similar relative differences in costs hold also in New Zealand.

5. Other methane reduction targets and their rationale

Some commentators and stakeholders have advocated a less stringent reduction target for agricultural methane than the 24-47% reduction range contained in the Zero Carbon Bill.

The key argument promoted is that methane should be reduced only to the point where it does not cause additional warming above today's level as this would then mirror the climate outcome of reducing emissions of long-lived gases to net-zero.

Supporters of this view argue that this would constitute an equitable and fair treatment of methane emitters compared to a net-zero target for emitters of long-lived greenhouse gases.

5.1 Scientific basis

The impacts on climate from different greenhouse gases are uncontested among climate scientists.

Emissions of carbon dioxide and nitrous oxide will continue to add further warming until their emission reach net zero, because their emissions accumulate in the atmosphere. Once net zero emissions of those gases are reached, their contribution to global warming would decline very slowly over a time scale of centuries (see Section 3.2).

Avoiding further warming from methane requires a much lesser reduction, given that methane does not accumulate in the atmosphere over centuries. A note by the Parliamentary Commissioner for the Environment last year showed that agricultural methane would need to be reduced by 10-22% by 2050, relative to 2016, to avoid any *additional* warming from New Zealand agricultural methane emissions above current levels; for technical details see Reisinger (2018).

The amount by which New Zealand's methane emissions have to be reduced to avoid additional warming is not a single fixed number but depends on actions undertaken by the rest of the world.

The reason for this is that how much the emission of one tonne of methane contributes to global warming depends on how much methane there is in the atmosphere already. The more methane is in the atmosphere already, the less additional warming an additional tonne of methane will cause.[6]

If countries globally reduce methane emissions by 2050 consistent with the goal of limiting the temperature increase to well below 2°C, the global methane concentration in 2050 could be considerably lower than today. In that case, any methane emitted by New Zealand would become more 'visible' in the atmosphere (i.e. more effective at absorbing heat radiation) and hence would cause more warming for each tonne emitted. As a result, New Zealand would have to reduce its methane emissions by 22% to avoid its emissions causing additional warming above current levels.

By contrast, if the world fails to reach the temperature goal of the Paris Agreement, global methane concentrations might not fall before 2050. In that case, New Zealand's methane emissions would have to be reduced by only about 10% to not cause additional warming.

Some scientists and stakeholders have promoted a single target of a 10% reduction for New Zealand's methane emissions as consistent with the goal of not adding to further warming. This is based on the notion that if *global* methane emissions from all sources were reduced by 10%, the contribution from methane to global warming would not increase above current levels.

However, while this is correct as a global thought experiment, New Zealand and the rest of the world are not identical. All global scenarios that limit warming to 1.5°C or even just well below 2°C reduce global methane emissions by a lot more than 10%. This is partly because a significant share of global

[6] This saturation effect is well recognized scientifically and incorporated in global models. An analogue to this saturation effect is that the voice of a single person is barely audible in a crowded room but highly audible in an empty hall.

methane emissions is tied to the extraction and use of fossil fuels, which would necessarily have to be reduced to meet the goal of the Paris Agreement (see Section 4.2).

If New Zealand as individual country wishes for its biogenic methane emissions to not cause additional warming above current levels, a 10% target by 2050 is applicable only if one assumes that the world as a whole does not reduce its methane emissions by more than 10% either. This is a significant assumption, as it would very likely mean that the temperature goal of the Paris Agreement will not be met (see Section 4.3). Whether this assumption is justified and should guide national decision-making is another matter that is not related to methane being a short-lived gas.

5.2 Equal additional warming vs equal effort: what does fairness mean?

The question of what emissions reductions are necessary to avoid additional warming from New Zealand's biogenic methane above current levels is fundamentally different to the question that is addressed by global models assessed by the IPCC.

A goal of 'not adding any additional warming from a specific gas from a specific country above the warming caused at present' is not based on any economic criteria and is not linked to a specific global temperature outcome. By design this goal ignores how much this gas contributes to global warming in absolute terms and whether future actions could reduce this contribution.

By contrast, the models assessed by the IPCC seek to achieve a given global temperature limit, relative to pre-industrial levels, at the least cost overall. By design they do not place pre-conditions on what contribution the future emissions of a given gas should make to future warming.

Given the long lifetime of carbon dioxide in the atmosphere, past emissions result in an almost constant level of warming for many centuries into the future. Future emissions of carbon dioxide will inevitably contribute additional warming on top of this historical legacy. Future emitters of carbon dioxide can at best avoid adding further warming, but they cannot undo historical warming caused by past emissions (past and future emitters are not necessarily the same entities).

Therefore, if emitters of carbon dioxide and other long-lived gases undertake maximum efforts to avoid future emissions, they can at best only achieve a goal of not creating additional warming.

By contrast, most of the warming caused by biogenic methane emitted up to 2019 will have disappeared naturally by 2050. This is a direct consequence of the relatively short lifetime of methane in the atmosphere. As a result, the contribution from biogenic methane to future global warming depends almost entirely on future emission levels and the actions taken by future emitters.

Therefore, if emitters of biogenic methane undertake maximum efforts to avoid future emissions, they could not only avoid creating additional warming but could reduce their contribution to warming well below the current contribution to global warming.

Figure 8 illustrates these differences by separating the past and future contributions to global warming that are due to past and to future emissions of fossil carbon dioxide and biogenic methane.

From a societal perspective, the question is whether we consider that the goal of 'treating sectors equally' is best served by ensuring that all sectors do not create additional warming above whatever warming they are contributing currently, or by undertaking similar efforts to reduce their emissions.

What constitutes equal efforts depends on the cost of emission reductions, current and future technologies, who actually bears such costs, and the broader societal implications of transformative change – it cannot be determined based on the atmospheric lifetime of methane.

Equal additional warming and equal effort are thus two fundamentally different things: for gases with significantly different lifetimes, causing the same additional warming above current levels almost certainly means not the same effort for emitters of those gases, and the same effort to reduce emissions almost certainly means not the same additional warming.

Future warming from a short-lived gas like biogenic methane is not an inescapable legacy of the past, it depends almost entirely on future emission choices. For biogenic methane, a target of 'not causing additional warming above current levels' therefore amounts to a grand-parenting approach, i.e. an entitlement to continue to emit methane in future at a level that is determined solely by past emissions regardless of abatement potential or cost. Like all grand-parenting approaches, this raises equity issues that cannot be resolved by climate science.

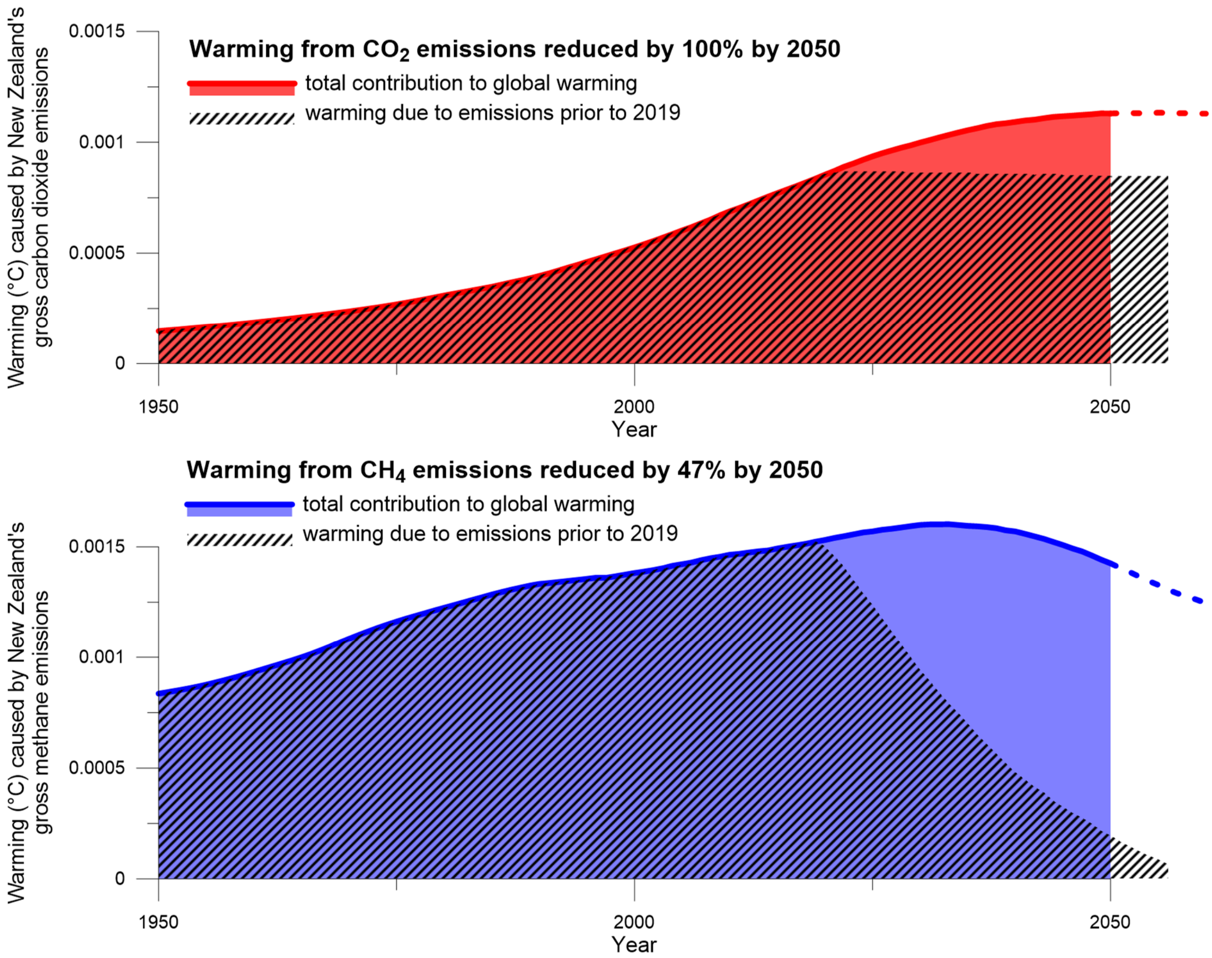

Figure 8. Total warming caused by New Zealand's gross (fossil) carbon dioxide and biogenic methane emissions, if carbon dioxide emissions reach net zero by 2050, and methane emissions are reduced by 47% by 2050 relative to 2017 levels. Hatched areas show the warming that is due to emissions that occurred prior to 2019, while solid areas show the warming that is additional to the warming caused by past emissions and that could be avoided by reducing future emissions. Dashed lines illustrate outcomes beyond 2050 if emission remain at constant levels from 2050 onwards.

Appendix I: warming from NZ under alternative global scenarios

The warming caused by emissions in New Zealand depends on how much of those gases is already present in the atmosphere. Different assumptions about global actions to reduce emissions can therefore influence how much warming would be caused by emissions in New Zealand. The warming from New Zealand's methane emissions is slightly less if the world undertakes less stringent emission reductions because this has a large impact on global methane concentrations, which in turn affects the warming efficacy of New Zealand's emissions; see Sections 3.3 and 5.1, also Reisinger (2018).

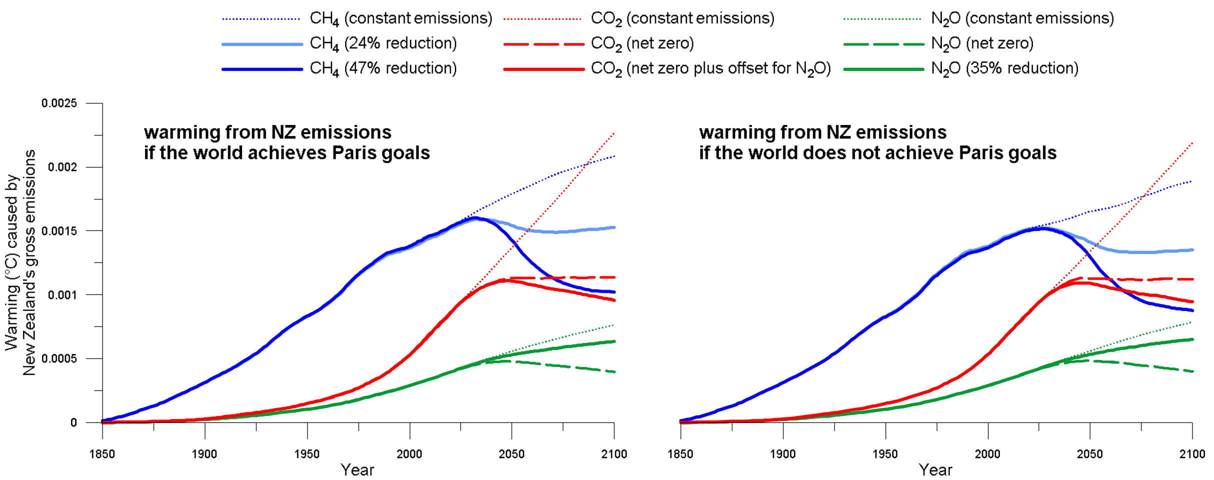

Figure 9. Contribution to global warming from individual greenhouse gases for emissions consistent with the Zero Carbon Bill. The left panel is identical to Figure 3, which assumes that the world reduces emissions by 2050 to achieve the temperature goal of the Paris Agreement. The right panel assumes that global emissions reductions are not sufficient to achieve the temperature goal of the Paris Agreement (resulting in warming of about 2.5°C above pre-industrial levels). New Zealand emissions are identical in both panels and are the same shown in the top panel of Figure 3. Technical note: for the left panel, the world follows the RCP26 pathway, for the right panel, it follows RCP45.

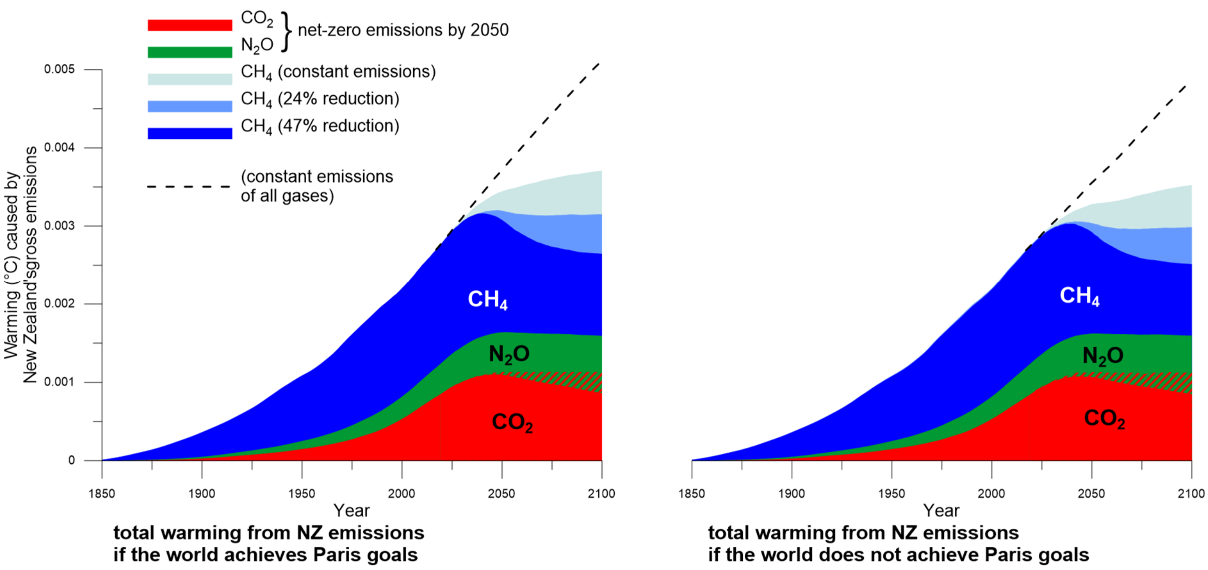

Figure 10. Combined contribution to global average temperature change from New Zealand's gross emissions of fossil carbon dioxide, nitrous oxide, and biogenic methane. The left panel is for an assumption that the world reduces emissions by 2050 to achieve the temperature goal of the Paris Agreement (identical to Figure 4). The right panel is for an assumption that the world does attempt to reduce emissions, but reductions are not sufficient to achieve the temperature goal of the Paris Agreement (resulting in warming of about 2.5°C above pre-industrial levels). New Zealand emissions are identical in both panels and are the same as in Figure 4. Technical note: for the left panel, the world follows the RCP26 pathway, for the right panel, it follows RCP45.

References

Ausseil, A.-G., M.U.F. Kirschbaum, R.M. Andrew, S. McNeill, J. Dymond, F. Carswell, N.W.H. Mason, 2013: Climate regulation in New Zealand: contribution of natural and managed ecosystems. In: *Ecosystem services in New Zealand – conditions and trends* [Dymond, J. (eds.)]. Manaaki Whenua Press, Lincoln, pp. 386-399.

Harmsen, M., D.P. van Vuuren, B.L. Bodirsky, J. Chateau, O. Durand-Lasserve, L. Drouet, O. Fricko, S. Fujimori, D.E.H.J. Gernaat, T. Hanaoka, J. Hilaire, K. Keramidas, G. Luderer, M.C.P. Moura, F. Sano, S.J. Smith, K. Wada, 2019: The role of methane in future climate strategies: mitigation potentials and climate impacts. *Climatic Change*, doi: 10.1007/s10584-019-02437-2.

IPCC, 2018: *Global Warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. [Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Pidcock, C.P.R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (eds.)]. Intergovernmental Panel on Climate Change, Geneva.

PCE, 2019: *Farms, forests, fossil fuels: the next great landscape transformation?* Parliamentary Commissioner for the Environment, Wellington, 183 pp.

Reisinger, A., 2018: *The contribution of methane emissions from New Zealand livestock to global warming*. Parliamentary Commissioner for the Environment, Wellington, 44 pp.

Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Séférian, M.V. Vilariño, 2018: Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (eds.)]. Intergovernmental Panel on Climate Change, Geneva, Switzerland, pp. 93-174.