Action on agricultural emissions

Technical appendix **4**

Achieving differentiated (split-gas) 2050 emission targets

Achieving differentiated (split-gas) 2050 emissions targets

1. Purpose

The Government consulted on the option of setting different 2050 targets for long-lived gases (primarily carbon dioxide, CO_2, and nitrous oxide, N_2O) and short-lived gases (methane, CH_4) in the Zero Carbon Bill. Given this option, the Committee has considered how policies to reduce agricultural greenhouse gas emissions (CH_4 and N_2O) could deliver differentiated (split-gas) targets.

This technical appendix provides more detailed analysis on the ways that the policy options considered by the Committee could achieve split-gas targets, and answers the question whether a split-gas target *necessarily* requires the use of separate policy instruments to address gases individually. It also includes a discussion of GHG metrics, to provide background to the Committee's view that the GWP_{100} metric is appropriate as starting point to any pricing policy to reduce agricultural CH_4 emissions.

2. Options and assessment criteria

This appendix outlines the Committee's assessment of the extent to which the following policies could deliver on separate targets for long-lived and short-lived gases:

- Emissions pricing policies
  - the New Zealand Emissions Trading Scheme (NZ ETS), with a single cap
  - an agricultural GHG levy/rebate scheme
  - a dual cap ETS or a methane quota system
- Non-price policies
  - Farm environment plans with prescribed Good Management Practices
  - Farm-specific emission limits

The suitability of these options for achieving split-gas targets has been assessed using the same six criteria outlined in section 1.4 of the Committee's report on agricultural emissions. The specific criteria that are most relevant for achieving split-gas targets are:

1. Reduce emissions, in a way that can accommodate different targets for different gases
2. Be cost-effective for the agriculture sector and for New Zealand
3. Be easy for farmers to understand and simple to comply with.

For the purposes of the analysis in this Technical Appendix, the third criterion has been split into its two parts – ease of understanding and implementation for farmers, and administration and transaction costs. Evaluation in this appendix focuses on how the policy options perform against each criteria specifically in a split-gas setting. For a more comprehensive assessment of the policy options, see Technical Appendix 3: Analysis of regulatory options against criteria.

The recent report by the Parliamentary Commissioner for the Environment (PCE 2019) proposed an alternative type of differentiated emissions target. That report proposed setting one target for gross fossil CO_2 emissions, and a separate net target for all land-based emissions and removals (comprising

CH_4 and N_2O from agriculture, and CO_2 from land-use and land-use change including sequestration of CO_2 from trees and vegetation). This approach is intended to result in higher emission prices for fossil CO_2 emissions and faster reductions of those emissions, and lower emissions prices for land-based emissions and removals. The difference in emissions prices would depend on the stringency of the target for fossil CO_2 and the net target for land-based emissions.

The Committee believes that its proposed long-term policy approach of a farm-level levy/rebate scheme for agricultural GHGs could easily be adapted to work with such an alternative target (for details, see the discussion of the farm-level levy/rebate scheme below).

If a split-gas target is adopted as part of the Zero Carbon Bill, this will have an impact on how emissions calculations are done and allocation is provided. For all of the options considered (with the exception of Farm Environment Plans with mandatory Good Management Practices – see below), the calculations and allocation can be done in a relatively straightforward way (see Box 1).

Box 1: Emission and allocation factors under a split-gas target

Emissions factors

In any policy with clear separation of long-lived and short-lived gases, the emission calculations by participants would have to be carried out for each gas individually. Emission calculations generally rely on Emission Factors (EFs) that relate an activity to an emission (see Technical Appendix 2: Calculation of Emissions). For example, if emissions were calculated using a simple method based on stock units, the emission calculation under a **single-basket target** would be:

$$Emission\ (CO_2e) = SU \times EF_{SU}^{CO2e}$$

where EF_{SU}^{CO2e} is the emission factor describing the national average emissions (in CO_2e) per stock unit, and where CH_4 and N_2O emissions have already been aggregated into CO_2-equivalent emissions. Under a **split-gas target**, the same formula would apply, but would be separated into CH_4 and N_2O emissions:

$$Emission\ (CH_4) = SU \times EF_{SU}^{CH4}$$

$$Emission\ (N_2O) = SU \times EF_{SU}^{N2O}$$

where EF_{SU}^{CH4} and EF_{SU}^{N2O} are the emission factors describing the national average CH_4 and N_2O emissions per stock unit. Calculating emissions for individual gases thus uses the same methodology and requires no additional activity data but requires twice the number of calculations and emission factors. This applies to any policy serving a split-gas target.

Allocation factors

The same approach applies to allocation factors (AFs), which are used to determine the amount of free allocation a participant in an emissions pricing scheme receives. For example, if output-based allocation is used (see Technical Appendix 5: Free Allocation), the allocation a participating dairy farm receives under a **single-basket approach** would be determined based on milk solids (MS):

$$Allocation\ (CO_2e) = output\ (MS) \times AF_{MS}^{CO2e} \times allocation\ rate\ (95\%)$$

where AF_{MS}^{CO2e} is the allocation factor describing the amount of emissions (in CO_2e) per kg MS that participants receive, which could be based on national average emissions per kg MS or reflect regional differences. Under a **split-gas approach**, the calculation of allocation would be done separately for each gas:

$$Allocation\ (CH_4) = output\ (MS) \times AF_{MS}^{CH4} \times allocation\ rate\ (95\%)$$

$$Allocation\ (N_2O) = output\ (MS) \times AF_{MS}^{N2O} \times allocation\ rate\ (95\%)$$

This separate allocation would apply to split-gas treatment within a levy/rebate scheme, dual cap ETS and methane quota system. It would also apply implicitly to the setting of farm-specific emission limits if those limits were to be set for individual gases.

As for calculating emissions, free allocation for individual gases would employ the same methodologies and underlying activity data (such as output, land area, stock units etc.) but would require twice the number of actual calculations and gas-specific allocation factors.

3. NZ ETS with a single cap

In the NZ ETS, as well as in New Zealand's reporting and accounting towards national emissions targets, exchange rates are used to transform amounts of the various greenhouse gases into a single unit, CO_2-equivalent (CO_2e). The exchange rates currently used are GWP_{100} values. GWP_{100} is the metric that is internationally-mandated for use in countries' GHG reporting to the UNFCCC[1] and has been used to define and account towards New Zealand's 2030 emissions target.[2]

The NZ ETS mostly covers carbon dioxide emissions, although synthetic GHG emissions and small amounts of N_2O and CH_4 from non-agricultural sources are also included. The unit of trade is the New Zealand Unit (NZU), which represents one tonne of CO_2e.

The NZ ETS currently uses a fixed exchange rate between different gases, based on the GWP_{100} metric, to translate emissions of individual gases into NZ ETS Units (NZUs). This approach results in different effective prices for different gases, depending on the GWP_{100} value applied. For example:

Effective emissions price per tonne of N_2O = GWP_{100} for N_2O x NZU price

Effective emissions price per tonne of CH_4 = GWP_{100} for CH_4 x NZU price

For an assumed NZU price of $25 per tonne of CO_2e, and GWP_{100} for N_2O of 298 and for CH_4 of 25, the effective emissions prices would be $7,450 per tonne of N_2O, and $625 per tonne of CH_4.[3]

The NZ ETS creates equal incentives to reduce 1 tCO_2e regardless of where those reductions occur and what gas is being abated. Under current settings, this sets up a potential discrepancy with a split-gas target, because abatement is driven solely by changing NZU prices, and CH_4 reductions achieved by 2050 may deviate from those specified in a split-gas target.

However, a lever to apply different pressure on different gases could be created by varying the exchange rate. For example, if CH_4 reductions turn out to be greater than those needed to achieve the long-term CH_4 target using GWP_{100}, the exchange rate could be reduced. Vice versa, if emissions reductions are less than needed to meet the target, the exchange rate could be increased. This modified exchange rate would alter the amount of NZUs that points of obligation have to surrender, and hence change the costs they face and their incentive to abate CH_4 emissions.[4]

---

1 See UNFCCC (2018) Report of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement 2018, Addendum 2: Decisions adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (FCCC/PA/CMA/2018/3/Add.2), Section D: metrics. https://unfccc.int/sites/default/files/resource/cma2018_3_add2%20final_advance.pdf

2 See https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/New%20Zealand/1/New%20Zealand%20INDC%202015.pdf

3 GWP values are updated regularly by the Intergovernmental Panel on Climate Change (IPCC), reflecting advances in science as well as rising greenhouse gas concentrations which influence these values over time. New Zealand committed in accounting towards its 2030 target to using GWP values from the IPCC's 4th Assessment Report (2007), which give a value of 25 for methane and 298 for nitrous oxide. These values were revised by the IPCC in its 5th Assessment Report (2013), which updated them to 28 for methane and 265 for nitrous oxide, but noted that the values could be increased to 34 and 298 if climate-carbon cycle feedbacks are considered. For additional detail on GWP calculations, see IPCC (2013) and Reisinger (2018).

4 The modified exchange rate could also be described as *modified exchange rate = GWP_{100} × target adjustment*, i.e. the GWP_{100}-based exchange rate would be adjusted over time to ensure that the separate CH_4 emissions target is met.

This would result in a modified formula:

Effective (<u>modified</u>) emissions price per tonne of CH_4 = <u>modified exchange rate</u> for CH_4 x NZU price

A practical example of how this would work for a farm included in the NZ ETS is as follows:

- An average dairy farm emits approx. 350 kg CH_4 and 10 kg N_2O per hectare per year.
- Using GWP_{100} exchange rates, this dairy farm emits 8.75 t CO_2e/ha of CH_4 (0.35 t CH_4/ha x 25) and 2.98 t CO_2e/ha of N_2O (0.01 t N_2O/ha x 298) . If included in the NZ ETS, this farm would have to surrender 11.73 NZUs per hectare per year.
- If CH_4 emissions were falling significantly faster than necessary to meet the separate long-term target for CH_4, the exchange rate for CH_4 might be reduced (e.g. from 25 to 10). In that case, this same farm's CH_4 emissions would now be calculated as 3.5 CO_2e/ha (0.35 t CH_4/ha x 10). Its calculated CO_2e emissions from N_2O would remain unchanged. Consequently, this farm's total CO_2e emissions per hectare would now be calculated as 6.5 t CO_2e/ha and it would have to surrender 6.5 NZUs per ha.
- The same adjustments for the exchange rate of methane would have to be applied to any free allocation given to farmers (see Box 1 and Technical Appendix 5: Free Allocation).
- Reducing the exchange rate would reduce the overall incentive to reduce emissions on-farm, and the relative benefits of reducing methane compared to nitrous oxide emissions.

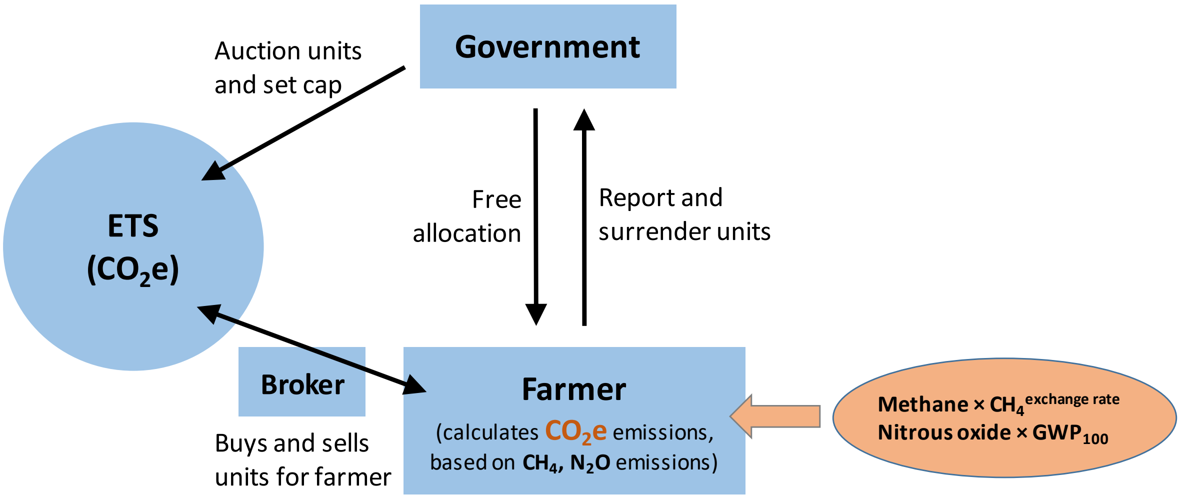
If the point of obligation were at processor level, altering the exchange rate for CH_4 would change the amount of NZUs that processors have to surrender. This would change the degree to which processors would have to reduce payouts to farmers, in turn altering the incentive for farmers to reduce emissions.

Varying the exchange rate in the NZ ETS would not affect how New Zealand reports on its emissions to the UNFCCC or accounts towards its 2030 target under the Paris Agreement – varying the exchange rate for CH_4 within the NZ ETS would be a purely domestic policy choice.

Apart from changing the exchange rate for CH_4, the government could also increase efforts on complementary measures to support emissions reductions if it wished to achieve greater CH_4 abatement than a given price achieves.

Figure 1 illustrates how the NZ ETS could operate with exchange rate adjustments for methane, if it covered agricultural methane and nitrous oxide.

NZ ETS with farm point of obligation



NZ ETS with processor point of obligation

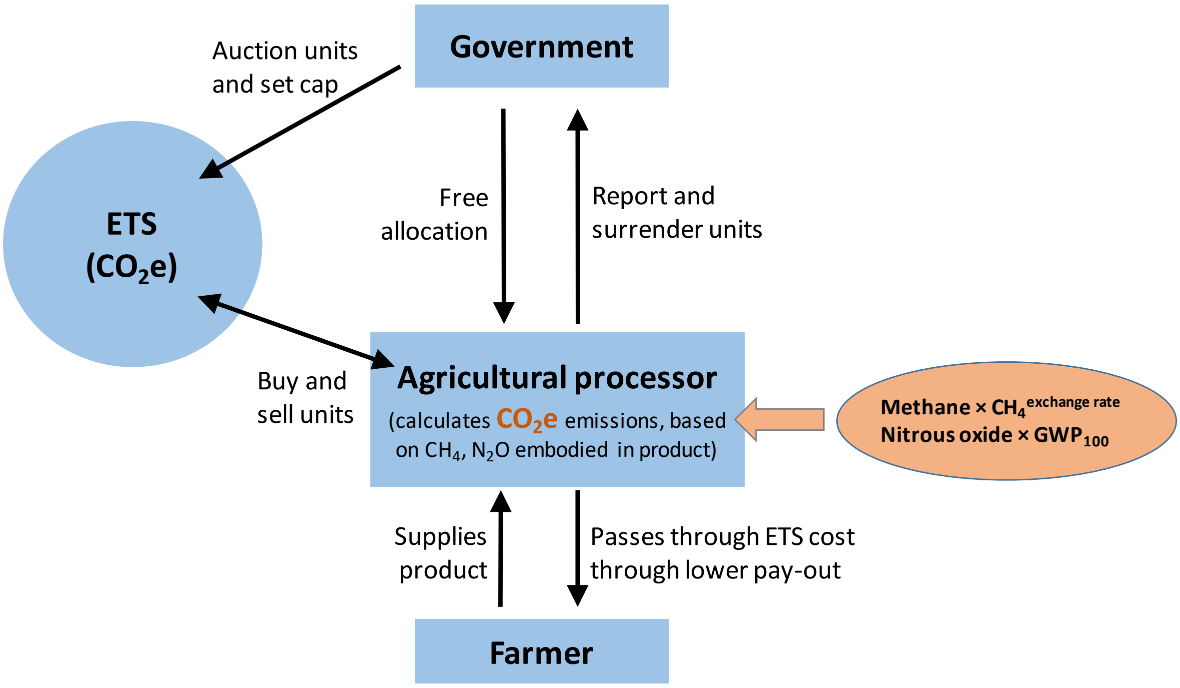


Figure 1. *Schematic arrangement of the treatment of agricultural GHG emissions in the NZ ETS, including a flexible exchange rate for agricultural methane to achieve a split-gas target. The top schematic is for a farm-level obligation, and the bottom schematic is for a processor-level obligation.*

The main challenges with this approach are that varying the exchange rate over time could:

a) introduce an additional element of future price uncertainty for participants
b) create an additional obstacle to linking the NZ ETS with schemes in other countries
c) be difficult for farmers and other stakeholders to understand.

To alleviate concerns with respect to (a), any changes to the exchange rate should only be made at specified points in time, based on advice from the Climate Change Commission (CCC). The CCC could make recommendations on the appropriate methane exchange rates at the same time as it provides advice on setting emissions budgets, and potentially also provide indicative advice on future changes between budgets. The CCC's advice would need to be based on an evaluation of whether CH_4 emission are tracking along a plausible pathway towards the 2050 target for CH_4. It should also consider risks and shocks to emitters and the New Zealand economy, and the need for gradual, predictable changes to support strategic investments.[5]

With respect to (b), the Committee heard concerns that if the exchange rate for CH_4 in the NZ ETS differs from the international norm (GWP_{100}) used in other emissions trading schemes, this could make linking the NZ ETS with other schemes harder. However, linking emissions trading schemes is already difficult and any linking between schemes would require significant negotiation and adjustments to some settings.

The Committee's view is that New Zealand's national circumstances, including its targets to reduce emissions, should be the primary driver of the design of domestic policy instruments like the NZ ETS. A different exchange rate for methane is likely to be only one of several issues that could hinder linking between the NZ ETS and other schemes (for example, no other ETS covers the forestry sector as the NZ ETS does). For these reasons, challenges to linking with other trading schemes should not rule out the option of adjusting the exchange rate for CH_4 in the NZ ETS to achieve split-gas targets.

Based on its discussions with sector representatives and farmers, the Committee considers that criterion (c), that a policy be easily understood by farmers and others, is a particularly important consideration. If exchange rates were adjusted over time in the NZ ETS, it may not be obvious and transparent to scheme participants or other observers that the focus on CH_4 emissions is different from that on emissions of other gases. This is because exchange rate adjustments would happen in the background, while emissions would still be calculated and reported in CO_2e, and there would still be only one NZU price in the market. For farmers, who given their predominantly small size would be likely to find participation in the NZ ETS challenging due to administration and transaction costs, this would add another layer of complexity and could reduce trust in the policy and its consistency with the expressed goal of treating CH_4 differently.

Table 1 summarises the Committee's assessment of the suitability of using a single cap NZ ETS with regular, gradual adjustments to the CH_4 exchange rate to deliver on split-gas targets. Note the high administration and transaction costs are a feature of a farm-level NZ ETS approach in general, they are not specific to a split-gas target.

5 In contrast to methane, the exchange rate for nitrous oxide (GWP_{100}) should only be updated if international reporting and accounting guidelines change, to ensure the incentive to abate nitrous oxide emissions matches the way New Zealand accounts towards its emission targets.

Table 1: *Assessment of a single cap NZ ETS against criteria.*

Option	Accommodates split-gas targets	Cost-effective	Easy for farmers to understand	Administration and transaction costs
NZ ETS (single cap, farm point of obligation)	✓	✓	✗	✗

Given the Committee's recommendation that agriculture be placed in the NZ ETS until 2025, and then progress to pricing livestock emissions through a levy/rebate scheme at farm scale, the Committee considers that there would be no need to vary the exchange rate within the NZ ETS in the short term. Using the exchange rate given by GWP_{100} is considered a plausible starting point for the first five years to 2025, given that New Zealand has committed to use this metric to account for its 2030 target (for additional considerations, see Section "Greenhouse gas metrics" below).

4. Pricing livestock emissions through a levy/rebate scheme at farm scale

An agricultural GHG levy/rebate scheme at farm-level would be very similar to pricing agricultural methane and nitrous oxide through the NZ ETS. The main difference would be that rather than experiencing a price on emissions through buying and surrendering units in the NZ ETS, farmers would pay a levy (or receive a rebate) based on their methane and nitrous oxide emissions, with the price on those emissions acting as incentive to reduce them.

The same considerations outlined above for the NZ ETS apply in principle to an agricultural GHG levy/rebate scheme at farm scale, but in a simpler and more transparent manner.

In summary, this policy could support achievement of split-gas targets as follows:

- The levy rate for each gas would be set in advance for each compliance year
- The levy rate for N_2O, as a long-lived gas, would be based on the average NZU price in the NZ ETS over the previous year, weighted using GWP_{100}:

  $$\textit{Levy rate per tonne of } N_20 = GWP_{100} \textit{ for } N_2O \times \textit{NZU price}$$

- The levy rate for CH_4 would be set independently and updated over time, such that actual emissions track towards the separate target for methane:

  $$\textit{Levy rate per tonne of } CH_4 = CH_4 \textit{ price}$$ [6]

The net levy or rebate due at farm level would depend on the amount of free allocation (see Box 1 and Technical Appendix 5: Free Allocation), which would have to be provided for individual gases.

As per the NZ ETS discussion, the CH_4 price would need to be updated routinely based on an assessment of whether CH_4 emissions are on a plausible pathway towards the 2050 CH_4 target , drawing on accumulating knowledge about emissions trends and abatements that farmers are making on farms in response to emissions prices. To manage uncertainty, any changes to the CH_4 price should only be made at specified points in time, based on advice from the CCC and considering risks and shocks to emitters and the New Zealand economy, and the need for gradual, predictable

[6] The CH_4 price could also be described as *CH_4 price = modified exchange rate × NZU price*, with the modified exchange rate as defined for the NZ ETS (see Footnote 4). Thus the NZ ETS and levy/rebate scheme create similar price incentives.

changes to support strategic investments. The CCC could make recommendations on the appropriate CH_4 prices at the same time as it provides advice on setting emissions budgets, and potentially also provide indicative advice on future CH_4 price changes between budgets.

While the CH_4 price would be determined in the long run purely by how CH_4 emissions are tracking towards the long-term 2050 target, there is a need to get started with a specific price. The actual emissions reductions in response to such an initial price will be critical to underpin advice given by the CCC on future adjustments to the CH_4 price.

The Committee considers that this *initial* price should mirror that for N_2O and be based on the NZU price and GWP_{100} exchange rate:

$$\textit{Levy rate per tonne of } CH_4 = GWP_{100} \textit{ for } CH_4 \times \textit{NZU price}$$

The key reasons for setting the methane price initially in this way are that it would provide continuity at farm level if processors initially have a surrender obligation in the NZ ETS until 2025 and that it matches the way that methane emissions are accounted for in New Zealand's 2030 target (for additional considerations, see Section "Greenhouse gas metrics" below). Decoupling of the levy rate for CH_4 from NZ ETS emissions prices should be undertaken once evidence about the actual on-farm abatement under a farm-level policy has accumulated and been evaluated.

Figure 2 illustrates how the NZ ETS could operate with exchange rate adjustments for methane, if it covered agricultural methane and nitrous oxide.

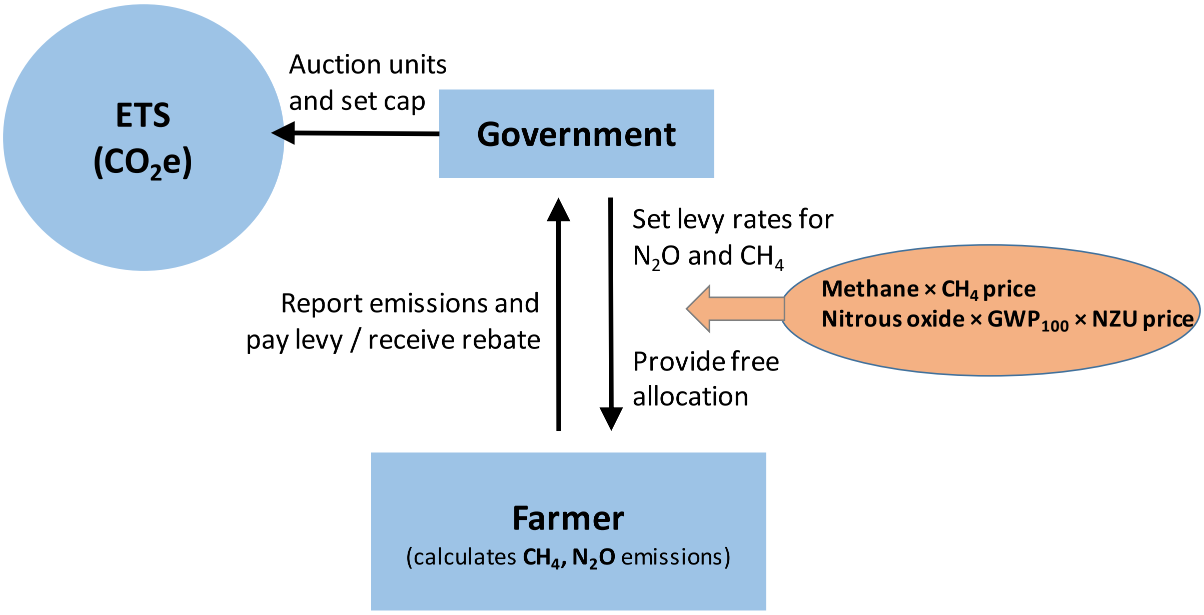


Figure 2. *Schematic arrangement of the treatment of agricultural GHG emissions in a levy/rebate scheme linked to the NZ ETS. The levy rate for N_2O would be determined by the cost of NZUs, while the levy rate for agricultural CH_4 would be set independently to achieve a split-gas target. The actual levy or rebate due at farm level would depend on emissions as well as the level of free allocation.*

Compared to altering exchange rates within a single cap NZ ETS, a farm-level agricultural GHG levy/rebate scheme has the following advantages (see also Technical Appendix 3):

- The different treatment of CH_4 would be transparent and clear to farmers and other stakeholders, as shown by the difference in the CH_4 levy rate as compared to the NZ ETS NZU price and resulting levy rate for N_2O.
- As noted in the agriculture report, a levy/rebate scheme would be simpler for farmers to participate in as compared to the NZ ETS, with lower administration and transaction costs.
- Different treatment of agricultural CH_4 would be confined to the levy/rebate scheme and would not affect the operation of the NZ ETS. This could mitigate any concerns about creating further hurdles in the way of linking the NZ ETS with other schemes.
- A levy/rebate scheme or NZ ETS both allow and support integrated decision-making at farm level, with full flexibility at farm level in how to respond to different emissions prices on different gases. This is a key difference to other policies considered, such as farm-level limits on individual gases or a methane quota system, which would preclude offsetting CH_4 emissions with carbon removals on-farm.

The overall assessment of this option against the criteria is found in Table 2.

Table 2: *Assessment of a levy/rebate scheme at farm scale against criteria.*

Option	Accommodates split-gas targets	Cost-effective	Easy for farmers to understand	Administration and transaction costs
Levy/rebate scheme	✓	✓	✓	✓

The farm-level levy/rebate scheme could in principle also be adapted to serve other differentiated emissions targets. For example, the recent report by the Parliamentary Commissioner for the Environment (PCE 2019) recommended a target for land-based emissions and removals only. If this were pursued, the levy rate for both N_2O and CH_4 emissions could be modified to track towards whatever target has been set for land-based emissions. This would avoid the price on N_2O emissions being driven by fossil CO_2 emitters and their demands for NZUs.

In this case, GWP_{100} could serve as an appropriate starting point for exchange rates amongst the gases included in this land-based basket of gases (see discussion in PCE 2019). This could be modified over time depending on how a specific land-sector based target is formulated and emissions are tracking towards such a net target. Details would depend on whether there is a desire to have fully flexible offsets between agricultural CH_4, N_2O and CO_2 removed from the atmosphere by planting trees.

5. Other price-based trading schemes: methane quota system, dual cap NZ ETS

Another option for delivering on a separate target for CH_4 would be to have a dedicated CH_4 policy instrument separated from the policy instrument for long-lived gases. Two ways of doing this have been proposed:[7]

- A dual cap NZ ETS
- A methane quota system, with the NZ ETS remaining the policy covering long-lived gases.

A methane quota system and dual cap ETS both explicitly prescribe the allowable amount of CH_4 emissions separately from emissions of other gases. Both instruments encourage participants to reduce emissions of CH_4 directly but allow trading; those who cannot reduce emissions themselves can meet their obligations by purchasing CH_4 quota/units from those who hold more quota/units than they are required to surrender in each period. For graphical illustrations of these approaches, see Figure 3.

The main reasons that the Committee has heard in support of this approach are that it would:

a) Isolate actions to reduce CH_4 emissions from actions in and costs faced by other sectors
b) Remove reliance on GHG exchange rates that are seen as scientifically contested
c) Provide greater certainty that the methane target will be achieved than an approach based on adjusting exchange rates in the NZ ETS or in a levy/rebate scheme.

In relation to (a), the creation of a dedicated trading scheme for a single gas indeed does fully isolate actions on CH_4 from actions in other sectors or on other gases.

In relation to (b), the Committee notes that setting a long-term emission target implicitly relies on an exchange rate between GHGs that informs what level of reductions (and cost of those reductions) is considered appropriate. The question is only whether such GHG exchange rates appear transparently within the policy instrument (e.g. the role of GWP_{100} in setting emissions prices for individual gases in the NZ ETS) or are embedded within the split-gas target.

In relation to (c), the Committee does not consider that the level of certainty that these policies would achieve a separate CH_4 target differs materially from the certainty offered by adjustments of exchange rates within price-based policies.

A key reason is that the methane cap in a dual cap ETS, or the methane quota, would need to be changed over time to progress towards the 2050 target. The path for successive CH_4 budgets is unlikely to be linear, given the inertia in making structural adjustments in the industry (e.g. de-intensification of high-input dairy systems with high debt levels and infrastructure investments), and the prospect of novel mitigation options in future.

If the costs and benefits of achieving successive, separate CH_4 budgets turn out to be higher or lower than what might be considered fair and reasonable for the agriculture sector, there will be political pressure to amend both short term CH_4 budgets and/or the long-term CH_4 target. This pressure is unlikely to be any different to the pressure associated with a change in the CH_4 exchange rate within the NZ ETS or the CH_4 levy rate at farm scale. The degree of transparency around whether CH_4 emissions are plausibly tracking towards their long-term target is the same.

[7] See e.g. Productivity Commission (2018)

A key downside of both a quota and dual cap ETS system is that they would significantly increase the administration and transaction costs for farmers overall. Farmers would have to comply with whatever policy instrument is in place to reduce N_2O emissions *in addition to* the quota or dual cap ETS system to address CH_4.

While the administrative cost for a dual cap ETS may not be much greater than for a single-basket ETS, it would create two separate units with separate markets and potentially separate brokerage fees to trade those different units at different times. The creation of two discrete policies for N_2O and CH_4 would also force famers to reconcile two separate sets of objectives in their on-farm decision-making. The Committee heard clear requests from farmers to reduce the number of separate objectives and policies that they must deal with on their farms.

Some stakeholders have argued that, even with a dual cap ETS or methane quota system, it should be possible for farmers to use units earned by forests on their farms to offset CH_4 liabilities. However, such an approach would undermine the ability of these policies to achieve a separate CH_4 target. This is because any non-CH_4 offsets within a CH_4 cap or quota would necessarily result in actual CH_4 emissions to be higher than the CH_4 target.

The only option to avoid this outcome would be to reduce the total CH_4 quota or cap in proportion to the total amount of carbon offsets entering the scheme. While this approach is possible in principle, it would negate the intended benefit of the dual cap ETS or methane quota system of isolating pressure on CH_4 from abatement options and costs of other gases. A dual cap ETS or methane quota system would therefore only be able to meet their design objective *and* deliver towards a split-gas target if no offsetting between CH_4 and CO_2 sequestration on-farm is allowed.

The overall assessment of this option against the criteria is contained in Table 3.

Table 3: *Assessment of a dual cap ETS or methane quota at farm scale against criteria.*

Option	Accommodates split-gas targets	Cost-effective	Easy for farmers to understand	Administration and transaction costs
Dual-cap ETS or methane quota	✓	✓	✘	✘

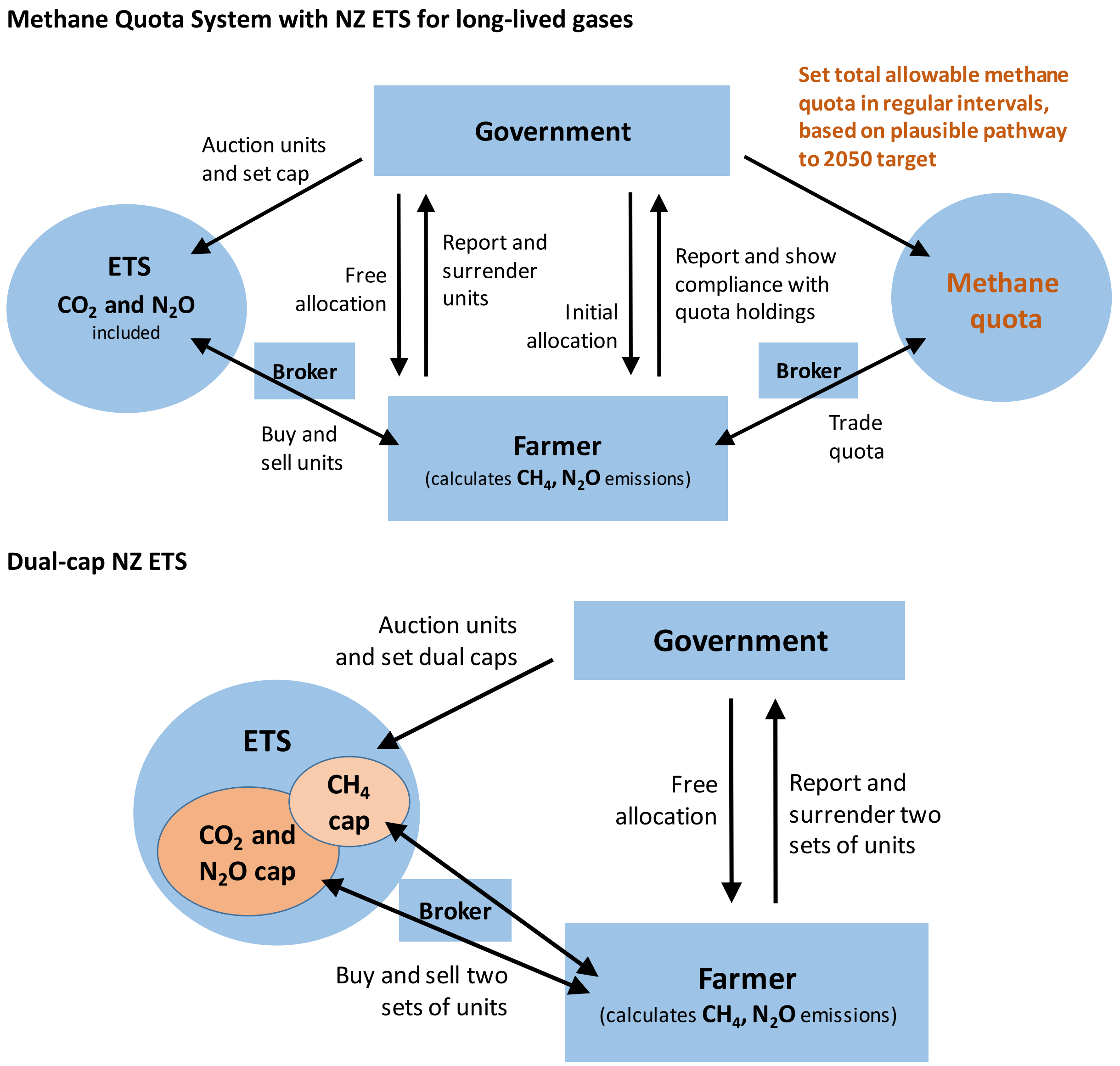


Figure 3. *Schematic arrangement of the treatment of agricultural GHG emissions in a (top) methane quota and (bottom) dual-cap ETS scheme. The schematic arrangements assume that there is no trading between methane and carbon sequestration on-farm.*

6. Farm Environment Plans with mandatory Good Management Practices

Farm Environment Plans (FEPs) combined with mandatory Good Management Practices (GMPs) would make achieving a differentiated emissions targets difficult. This is because GMPs, as far as they could currently be envisaged, would have limited effect on emissions of any gas if implemented as part of a compliance regime (see Figure 4 and more detailed analysis in Technical Appendix 3).

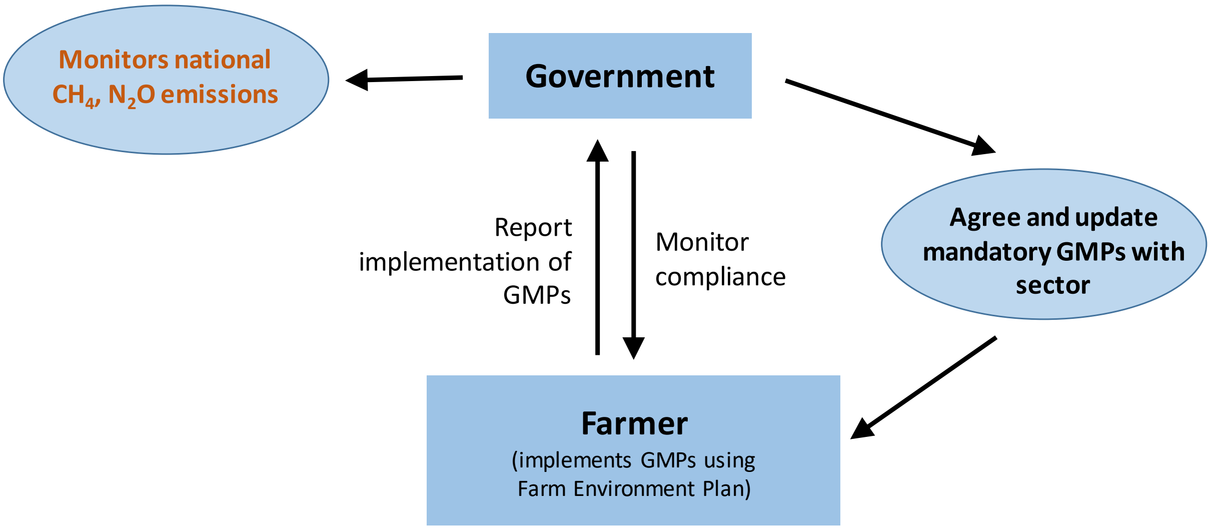


Figure 4. *Schematic illustration of how Farm Environment Plans with mandatory Good Management Practices (GMPs) would address a split-gas target.*

If emission reductions are achieved by more ambitious farm-optimisation (using the principles in GMPs as guide rather than a prescriptive yes/no implementation), it would be difficult to predict or manage the outcome on individual gases, because the way the GMP principles are interpreted could vary from farm to farm.

For example, if a greenhouse gas GMP stipulated that farms should minimise replacement rates, then same farmers might apply this principle to reduce overall stock numbers and retire the least productive and uneconomic parts of their farm, resulting in reductions of both CH_4 and N_2O. Other farmers might use a lower number of replacement animals to increase the number of productive animals such that both CH_4 and N_2O emissions remain unchanged or even increase.

A similar problem would occur if Farm Environment Plans were used with prescribed input limits such as maximum stocking rates or use of fertiliser per hectare, since farmers would be able to respond to such limits in different ways and with very different consequences for emissions. For example, if a limit was placed on stocking rates, farmers could increase supplementary feeds to increase production and emissions per animal and per hectare, or alternatively move towards a low-input operation with lower production and lower emissions overall.

Some gas-specific mitigation technologies such as a CH_4 inhibitor or vaccine would not be affected by this problem. In these cases, GMPs that require the use of such technologies would be able to clearly drive reductions of specific gases. However, even in this case, it might be difficult to achieve a specific emissions target; e.g. if a CH_4 inhibitor achieves a 20% reduction but the long-term target was a 30% reduction, additional measures would still be needed. Conversely, if the inhibitor achieves a 20% reduction but the target was for only a 10% reduction in CH_4, it would appear highly inefficient to aim for only 50% of farmers adopting the inhibitor.

The overall assessment of this option against the criteria is contained in Table 4.

Table 4: *Assessment of farm environment plans with mandatory good management practices against criteria.*

Option	Accommodates split-gas targets	Cost-effective	Easy for farmers to understand	Administration and transaction costs
FEPs with prescribed GMPs	✘	✘	✓	✓

7. Farm-specific emission limits

If emission limits were set separately for individual gases (i.e. CH_4 and N_2O) for individual farms, this would by definition provide a clear and transparent mechanism to achieve an overall differentiated emissions target (see illustration in Figure 5).

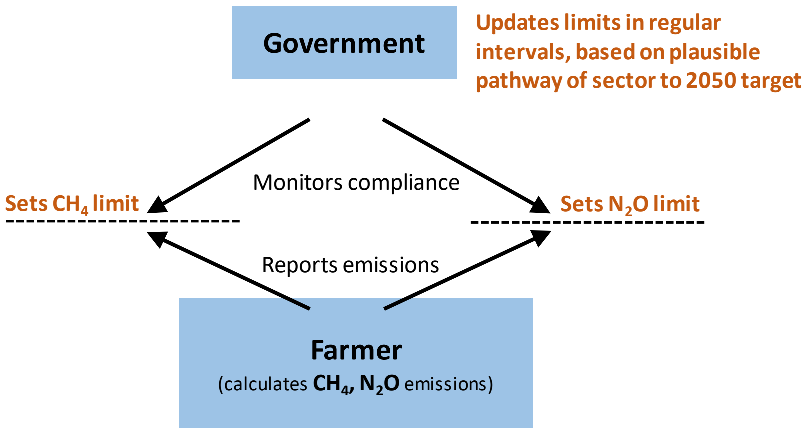


Figure 5. *Schematic arrangement of the treatment of agricultural GHG emissions in an approach based on Farm Environment Plans and farm-level emission limits.*

However, it is challenging to set farm-specific emission limits that reflect the actual abatement options and costs across diverse farming operations (see detailed analysis of farm-level emission limits in Technical Appendix 3: Criteria by Criteria Analysis). This makes an approach based on farm-specific emission limits not cost-effective.

Setting separate CH_4 and N_2O emission limits for each farm would also further constrain the flexibility of farmers to respond to multiple pressures and thus would reduce the cost-effectiveness of a greenhouse gas emission limits-based approach even further. Offsetting CH_4 emissions with carbon removals would be impossible because, as for a methane quota system, any non-CH_4 offsets within a CH_4 limit would necessarily result in actual CH_4 emissions to be higher than the CH_4 target.

An added complication is that if farm specific emission limits were used, these limits would have to be updated routinely for each farm (e.g. for 2025, 2030 etc) to determine the appropriate pace of action and monitor compliance within a sector-wide long-term 2050 target. Limits for individual gases might also need to be changed over time in response to new mitigation technologies, such as a CH_4 inhibitor, that may not be applicable equally across all farm types

The overall assessment of this option against the criteria is contained in Table 5.

Table 5: *Assessment of farm-specific emissions limits against criteria.*

Option	Accommodates split-gas targets	Cost-effective	Easy for farmers to understand	Administration and transaction costs
Emissions limits	✓	✗	✓	✓

8. Summary and conclusions

Table 6 summarises the assessment of the policy options against the criteria.

Table 6: *Summary assessment of policy options against criteria.*

Option	Accommodates split-gas targets	Cost-effective	Easy for farmers to understand	Administration and transaction costs
NZ ETS (single cap, farm point of obligation)	✓	✓	✗	✗
Levy/rebate scheme	✓	✓	✓	✓
Dual-cap ETS or methane quota	✓	✓	✗	✗
FEPs with prescribed GMPs	✗	✗	✓	✓
Emissions limits at farm level	✓	✗	✓	✓

Based on this assessment, the Committee does not consider that there is an inherent necessity to adopt separate policy instruments for different gases to meet a differentiated (split-gas) long-term emission target for 2050.

In both the NZ ETS and levy/rebate approach, the differentiated target could be achieved by adjusting a single lever within the policy, namely the CH_4 exchange rate (in the case of the NZ ETS) or the CH_4 emissions price (in the case of the levy/rebate scheme). Adjustments to the exchange rate or emissions price are simple and transparent and could be undertaken as an integral part of setting future emissions budgets, with indicative advice in between budgets.

The relative simplicity and cost-effectiveness of the farm-level levy/rebate scheme is still retained if a split gas approach is accommodated by varying the CH_4 price. It would preserve its integrity as long as any changes to the CH_4 price are subject to advice from the Climate Change Commission and then implemented via regulations that require their own consultation processes.

Such regular adjustments would provide for a simple and transparent mechanism to treat CH_4 differently to other greenhouse gases without the need to create separate policy instruments.

The Committee considers that pricing agricultural emissions through and linked to the NZ ETS using the existing GWP_{100} exchange rate would be appropriate for the first five years while agriculture emissions are priced at processor level, and for the start of the farm-level levy/rebate scheme. Decoupling of the levy rate for CH_4 from NZ ETS emission prices should be undertaken once evidence about the actual on-farm abatement under a farm-level policy has accumulated and been evaluated.

Box 2: Relationship between long-term target and policies to achieve the target

In evaluating policy options for the ability to achieve split-gas targets, we assumed that the stringency of policies would be adjusted so that any differentiated 2050 targets that might be contained in the Zero Carbon Bill are indeed met.

While a fixed long-term emissions target provides certainty, it can also have unintended consequences. If meeting a specific 2050 target for CH_4 turns out to be much costlier or more socially disruptive than anticipated at the time the Zero Carbon Act is passed, then it could be argued that the target itself should be adjusted to a less ambitious level.

Conversely, if it turns out that the 2050 target for CH_4 can be met at much lower costs and effort than anticipated (e.g. because of the arrival of a novel, low-cost mitigation technology, changes in international markets or attractive alternative land-uses), it could be argued that the ambition of the target should be increased.

Such future revisions would be fully consistent with the underlying science of climate change, which is clear that the lower total CH_4 emissions can fall, the lower New Zealand's overall contribution to climate change will be.

A balance is thus required between treating a long-term emissions target as cast in stone and adjusting the target in response to new information about benefits and costs of CH_4 reductions.

Given the uncertainty about potential changes in international markets and the availability, efficacy and cost of new mitigation approaches, the Committee considers it essential to routinely re-evaluate the target, using accumulating evidence about the actual effort required to reach the split-gas target and the social, economic and distributional consequences.

It may be desirable to have clear provisions in the Zero Carbon Bill on how and why a split-gas target was set initially, as well as the conditions and criteria under which the 2050 emissions targets should be re-evaluated, with a clear role for the Climate Change Commission to provide relevant advice and recommendations for any changes to the targets. Key policy settings such as the exchange rate or price for CH_4 could then be adjusted transparently, following the logic set out here, to help achieve any revised long-term target.

Addendum: Greenhouse gas metrics

Greenhouse gas metrics provide exchange rates between emissions of different gases. Their intention is to allow a quick and easy answer to the question of how the impact on climate from emitting one tonne of a certain gas compares with the impact from emitting one tonne of another gas. Conversely, they are intended to support decisions on how much effort and cost should be placed on reducing or avoiding the emission of a quantity of one gas compared with reducing or avoiding the emissions of a quantity of another gas.

The greenhouse gas metric mandated for reporting under the Paris Agreement is GWP_{100}, and New Zealand has committed to use this metric to account towards its 2030 emissions target. However, this does not mean that New Zealand must use this metric for domestic policy. New Zealand could also define future emission targets after 2030 using different metrics, as long as the contribution of New Zealand towards achieving global climate change goals is becoming more ambitious over time.

Up to 2030, using a metric other than GWP_{100} in domestic climate policy would mean that some emitters would face lesser incentives to reduce their emissions, while others would have to reduce their emissions even more, and at higher overall cost to achieve the same emissions target.

Nonetheless, there has been a lively debate in New Zealand, as well as in parts of the scientific literature, about how to best account for emissions of short-lived greenhouse gases such as CH_4, and how to compare CH_4 emissions with those of long-lived greenhouse gases, particularly CO_2.

In practice, such comparisons have to take into account two factors. One is that greenhouse gases differ widely in their ability to absorb heat radiation and thus add to the greenhouse effect. The second is that the effective lifetime of greenhouse gases in the atmosphere also differs widely. Some gases decay naturally over the course of a few decades, while others take many centuries and even millennia to disappear after they have been emitted.

Methane decays gradually in the atmosphere, with an effective lifetime of 12.4 years. Almost all of a methane emission will have disappeared from the atmosphere after about 50 years. In contrast, carbon dioxide lasts much longer, with about 40% of a single emission remaining in the atmosphere for many centuries, and a fraction even for millennia. Nitrous oxide has a lifetime of about 121 years, which makes it long-lived by human standards but not as long-lived as carbon dioxide (Myhre *et al.*, 2013). In terms of ability to trap heat, nitrous oxide is by far the most potent on a molecule-by-molecule basis, followed by methane, with carbon dioxide having the lowest ability to trap heat.

The consequences of these different properties are illustrated in Figure 6, which shows the actual warming caused by the emission of one tonne of carbon dioxide, methane and nitrous oxide each over 200 years following their emission (Reisinger, 2018; PCE, 2019).

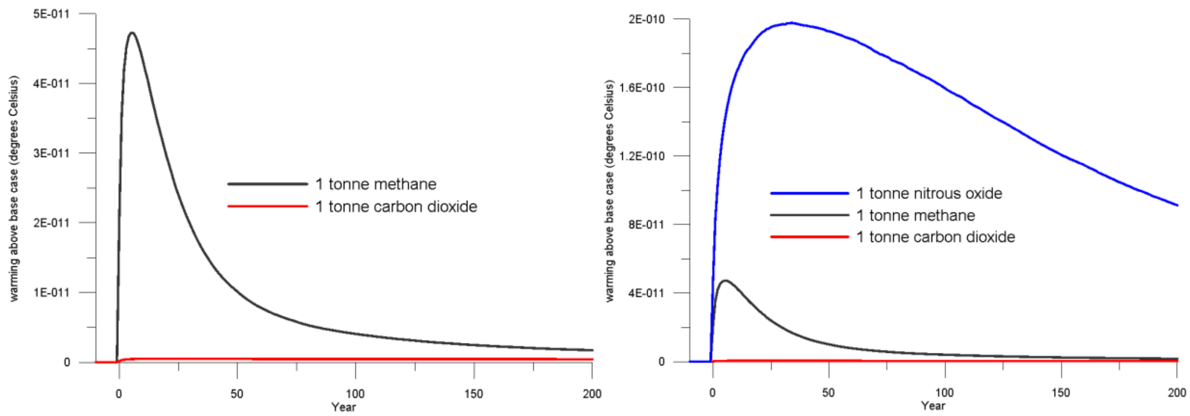


Figure 6. *Warming caused by the one-off emission of one tonne of nitrous oxide, methane, and carbon dioxide. The left panel compares the warming caused by one tonne of methane with that from one tonne of carbon dioxide, while the right panel compares the warming caused by warming from all three gases. Warming has been calculated using the methodology of Reisinger (2018), consistent with results obtained by other studies (e.g. Gillett and Matthews, 2010; Myhre et al., 2013; Gasser et al., 2016; Sterner and Johansson, 2017).*

The differing lifetimes of gases introduce an inevitable degree of subjectivity when comparing their climatic effects, since the impact of emitting a tonne of gas (and hence the value of avoiding the emission) depends on how far into the future we consider impacts on the climate and relies on us estimating the damages that their warming will cause far into the future. It also depends on whether and how much we wish to discount damages that occur further into the future, compared to damages that arise in the near term.

Figure 6 illustrates that over the next 200 years emitting one additional tonne of methane causes more warming at any point in time than emitting one additional tonne of carbon dioxide.

Given that climate change impacts are linked to warming, emitting one tonne of methane today causes substantially more damage to society and ecosystems affected by climate change, at least over the next several centuries, than emitting one tonne of carbon dioxide today. However, *how much more* damaging an emission of methane is compared to carbon dioxide depends on whether we are concerned with warming over the next 20 to 50 years, where the warming from methane is much greater, or only the warming in the more distant future (see e.g. Boucher, 2012; Shindell *et al.*, 2017; Sarofim and Giordano, 2018).

Fortunately, we are not emitting all greenhouse gases in equal quantities. Figure 7 shows the warming caused by New Zealand's actual gross emissions of CO_2, CH_4 and N_2O in the year 2016, compared to if those emissions had not occurred. For New Zealand's emissions profile, CH_4 emissions are causing the most warming over the next few decades, but in the longer term, the weaker but longer lasting warming from CO_2 dominates, given the much larger quantity of emissions.

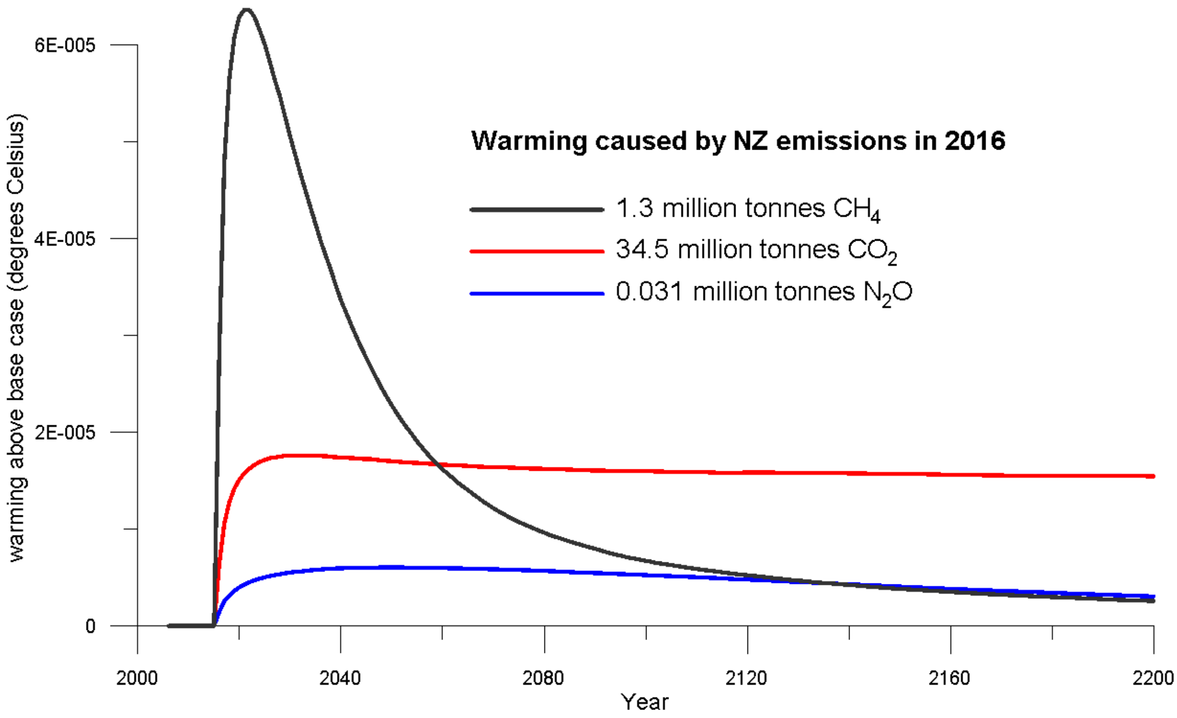


Figure 7. *Warming caused by New Zealand's actual gross emissions of nitrous oxide, methane, and fossil carbon dioxide in the year 2016.*

A range of different metrics has been designed to facilitate the comparison of the climatic impacts from annual emissions of different gases. The Global Warming Potential (GWP) compares gases based on the aggregate radiative forcing (the energy imbalance between incoming solar radiation and heat energy being radiated back into space). By contrast, the Global Temperature change Potential (GTP) compares gases based on the actual warming they cause at a specific single future point in time. Both GWP and GTP depend on specific time horizons (i.e. how far into the future the climate effects of each gas are considered).

These metrics are used widely in the scientific literature and in policy applications to compare discrete emission pulses of different gases. The table below shows the numerical values, illustrating that the choice of time horizon has a major influence on the exchange rate for CH_4, which has a relatively short lifetime, compared to the long-lived greenhouse gas CO_2 (which is used as reference gas in these comparisons). By contrast, the exchange rate for N_2O is relatively independent of the time horizon and even the metric, given that its rate of atmospheric decay is similar to CO_2, at least over the first 100 years after an emission.

There is wide agreement across scientists that the appropriate choice of metric cannot be determined by science alone but depends on broader policy contexts and goals, underlying value judgements (IPCC, 2009; Tanaka *et al.*, 2013; Hollis *et al.*, 2016; Levasseur *et al.*, 2016).

Table 7: *GWP and GTP values for different time horizons for CH_4 and N_2O, relative to CO_2. Values are from the latest assessment of the Intergovernmental Panel on Climate Change (IPCC 2013), including best estimates for climate-carbon cycle feedbacks. Also shown are the values chosen by New Zealand to account for its 2030 emissions target are also shown (GWP_{100}^{UNFCCC}), which are based on a previous IPCC assessment (IPCC 2007).*

	GWP_{20}	GWP_{100}	GTP_{20}	GTP_{100}	GWP_{100}^{UNFCCC}
CH_4	86	34	70	11	25
N_2O	268	298	284	297	298

Comparing individual yearly emissions is only one side of the story. Due to the slow rate of breakdown, every emission of CO_2 adds to the concentration of carbon dioxide in the atmosphere. This cumulative effect means that net emissions of CO_2, and other long-lived greenhouse gases such as N_2O, must be reduced to zero to stop adding to existing warming. The sooner we reach net zero emissions of these gases, the less we will contribute to global warming.[8]

If methane is emitted at a constant rate, methane concentrations will stabilise within about 50 years, as each new emission simply replaces a previous emission that is decaying naturally. Therefore, because methane does not accumulate methane emissions do not have to drop to zero to stop them adding to global warming.

The recently developed GWP* metric is designed to capture these key differences between CH_4 and CO_2 (Allen *et al.*, 2016; Allen *et al.*, 2018). The GWP* metric does not compare the climatic effect of *annual* emissions but compares a *sustained change* in CH_4 emissions with a *one-off* emission of CO_2.

While the GWP* metric is potentially very useful for evaluating different choices for long-term climate targets, it has limited utility in domestic policy instruments. This is because the GWP* metric is defined for a sustained (in perpetuity) change of CH_4 emissions. This built-in assumption means that it places a hundred-fold higher value on any change in CH_4 emissions than the GWP_{100} metric places on annual emissions of methane. [9]

In practice, emitters do not make decisions about future CH_4 emissions in perpetuity. Emissions from individual enterprises vary annually due to environmental and market conditions and even with what might be considered more permanent changes, such as reduced or increased stock numbers, there is no commitment to maintain these in perpetuity. This makes using GWP* for policies relying on annual emissions pricing problematic. For example, if a dairy farmer increased dairy cow numbers by one cow in a given year, and that cow emits 100 kg of methane, this would be the equivalent of

[8] A strong argument can be made to focus on reducing gross emissions, especially of fossil CO_2, rather than relying on tree planting to offset emissions (PCE 2019). Nonetheless, the world will continue to add to further warming until long-lived greenhouse gases collectively reach net zero emissions.

[9] The GWP* metric continues to be refined by its authors to better match the detailed understanding of how the climate system responds to greenhouse gas emissions, including cumulative warming effects from CH_4 emissions. In the most recent published version (Allen et al. 2018), a sustained rate of CH_4 emissions of 1 tonne is equated to a one-off emission of 2,800 tonnes of CO_2, based on the latest assessment by the Intergovernmental Panel on Climate Change of the Global Warming Potential of CH_4 and excluding climate-carbon cycle feedbacks. By comparison, under the standard GWP metric, a one-off emission of 1 tonne of CH_4 is equated to a one-off emission of 28 tonnes of CO_2.

emitting 280 tonnes of CO_2 in that year under the GWP* metric. At a carbon dioxide price of $25/tonne this would incur a one-off liability of $7,000.

The cost could be spread over an extended period to avoid the full liability (or benefit, if emissions are reduced in a given year) arising in a single year – but this would create challenges to track emissions over extended periods and would make the GWP* metric more similar to GWP the longer the time period used.

The GWP* metric has been very useful in confirming that when setting targets, there is a strong scientific rationale for the differential treatment of different gases: for long-lived gases not to add any further warming their net emissions need to be reduced to zero as quickly as possible, whereas methane emissions have to be reduced but not to zero.

Given the focus of the GWP* metric on changes in CH_4 emissions, some commentators have drawn the conclusion that if farmers reduce emissions below those needed to ensure that methane adds no further to warming, they should be rewarded for these reductions on the grounds that they are now cooling the planet. However, this perspective does not consider the degree to which sustained CH_4 emissions at any level are keeping Earth warmer than it would be without those emissions.

It also implies an assumption that the warming caused by CH_4 to date is the socially appropriate amount for those industries emitting methane – effectively this would create a grand-parented entitlement to a certain level of warming being sustained into the future.

A recent report by the Parliamentary Commissioner for the Environment (PCE 2019) shows that New Zealand's current rate of CH_4 emissions is responsible for significantly more warming at present than the cumulative fossil CO_2 emissions since the mid-1800s.

Even though on-going CH_4 emissions at the current rate would not add much more above current warming, reducing future CH_4 emissions could substantially reduce future warming.

Put simply, the less CH_4 we emit in future, the less we will contribute to future global warming.

How much methane should be reduced is a value judgement about how much total warming we are prepared to cause. Natural science alone cannot answer this question, nor tell us how to prioritise methane reductions now relative to reductions in long-lived gases.

This depends on our relative concern about climate impacts at different points in time, as well as political judgement on the extent to which effort to reduce one gas might displace efforts to reduce the other. Choices will also depend on how society weights the impacts on current and future generations, different expectations about humans' ability to adapt, to innovate, and to transition toward a low-emissions society without undue social cost.

Reducing CH_4 emissions, in addition to bringing emissions of long-lived greenhouse gases to or below net zero, has been identified consistently to play an important role to help achieve the ambitious temperature goals set out in the Paris Agreement (e.g. IPCC 2018; Collins et al. 2018; Nisbet et al. 2019; Rogelj et al. 2018).

In the policy approach recommended by the Committee, the incentive for farmers to reduce CH_4 emissions would be adapted over time to match whatever long-term emissions target is decided. The price on CH_4 emissions would be adjusted directly based on accumulating evidence of how actual emissions are tracking and the options and costs to reduce emissions. This makes decisions about metrics much less important.

The Committee considers the GWP_{100} metric adequate to set the price for CH_4 initially, provided that long-term emission targets are in place that can guide subsequent adjustments. This is because:

- considering the impacts on climate from today's emissions over the next 100 years, as the GWP_{100} does, is a sufficiently plausible starting point to compare the benefits of reducing the emissions of different gases
- New Zealand uses the GWP_{100} metric to account towards its 2030 emissions target.

References

Allen, M.R., J.S. Fuglestvedt, K.P. Shine, A. Reisinger, R.T. Pierrehumbert, P.M. Forster, 2016: New use of global warming potentials to compare cumulative and short-lived climate pollutants. *Nature Clim. Change*, **6**, 773–776.

Allen, M.R., K.P. Shine, J.S. Fuglestvedt, R.J. Millar, M. Cain, D.J. Frame, A.H. Macey, 2018: A solution to the misrepresentations of CO_2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. *npj Climate and Atmospheric Science*, **1**, 16 (DOI: 10.1038/s41612-018-0026-8).

Boucher, O., 2012: Comparison of physically- and economically-based CO2-equivalences for methane. *Earth Syst. Dynam.*, **3(1)**, 49-61.

Collins, W.J. et al., 2018: Increased importance of methane reduction for a 1.5 degree target. *Environmental Research Letters, **13**, 054003.*

Gasser, T., G.P. Peters, J.S. Fuglestvedt, W.J. Collins, D.T. Shindell, P. Ciais, 2016: Accounting for the climate-carbon feedback in emission metrics. *Earth Syst. Dynam. Discuss.*, **2016**, 1-29.

Gillett, N.P., H.D. Matthews, 2010: Accounting for carbon cycle feedbacks in a comparison of the global warming effects of greenhouse gases. *Environmental Research Letters*, **5(3)**, 034011.

Hollis, M., C. de Klein, D. Frame, M. Harvey, M. Manning, A. Reisinger, S. Kerr, A. Robinson, 2016: *Cows, Sheep and Science: A Scientific Perspective on Biological Emissions from Agriculture. Motu Working Paper 16-17*. Motu Economic and Policy Research, Wellington, 48 pp.

IPCC, 2009: *Meeting Report of the Expert Meeting on the Science of Alternative Metrics*. [Plattner, G.-K., Stocker, T.F., Midgley, P., Tignor, M. (eds.)]. IPCC WGI Technical Support Unit, Bern, Switzerland, 75 pp.

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., et al. (eds)] Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Levasseur, A., O. Cavalett, J.S. Fuglestvedt, T. Gasser, D.J.A. Johansson, S.V. Jørgensen, M. Raugei, A. Reisinger, G. Schivley, A. Strømman, K. Tanaka, F. Cherubini, 2016: Enhancing life cycle impact assessment from climate science: review of recent findings and recommendations for application to LCA. *Ecological Indicators*, **71**, 163-174.

Nisbet, E.G. et al., 2019: Very Strong Atmospheric Methane Growth in the 4 Years 2014–2017: Implications for the Paris Agreement. *Global Biogeochemical Cycles,* **33**, 318–342.

Myhre, G., et al., 2013: Chapter 8: Anthropogenic and Natural Radiative Forcing. In: *Climate Change 2013: The scientific basis. Contribution of Working Group I to the 5th Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., et al. (eds.)]. Cambridge University Press, Cambridge, UK, and New York, USA.

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. et al. 2018: Scenarios towards limiting global mean temperature increase below 1.5°C. *Nature Climate Change,* **8**, 325-332.
Sarofim, M.C., M.R. Giordano, 2018: A quantitative approach to evaluating the GWP timescale through implicit discount rates. *Earth Syst. Dynam.*, **9(3)**, 1013-1024.
Shindell, D.T., J.S. Fuglestvedt, W.J. Collins, 2017: The social cost of methane: theory and applications. *Faraday Discussions*, **200(0)**, 429-451.
Sterner, E.O., D.J.A. Johansson, 2017: The effect of climate–carbon cycle feedbacks on emission metrics. *Environmental Research Letters*, **12(3)**, 034019.
Tanaka, K., D.J.A. Johansson, B.C. O'Neill, J.S. Fuglestvedt, 2013: Emission metrics under the 2 °C climate stabilization target. *Climatic Change*, **117(4)**, 933-941.