Ministry for Primary Industries
Manatū Ahu Matua

Modelling Agriculture's Contribution to New Zealand's Contribution to the Post-2020 Agreement

MPI Information Paper No: 2016/02

Prepared for the Ministry for Primary Industries by
Andy Reisinger, Deputy Director, New Zealand Agricultural Greenhouse Gas Research Centre
Harry Clark, Director, New Zealand Agricultural Greenhouse Gas Research Centre
Additional input in support of this work has been provided by the following individuals:
Greg Lambert, Dave Clark (consultants)
Mike Rollo (AgResearch)
Paul Melville, Simon Wear, Rod Forbes (MPI)

ISBN No: 978-1-77665-169-6 (online)
ISSN No: 2253-394X (online)

February 2016

New Zealand Government

Growing and Protecting New Zealand

Table of Contents

Executive Summary

Approach

The report provides emissions data obtained from a range of emissions scenarios (baselines and targeted mitigation actions to reduce absolute emissions and/or emissions intensities relative to baselines) through until the year 2050, with a specific focus on 2030. The analysis uses New Zealand's national greenhouse gas emissions inventory and reporting tool as the primary vehicle to estimate emissions and the effectiveness of different mitigation options. This ensures that any actions taken could in fact be reflected in the national inventory and hence could be used to support any commitments by New Zealand.

We combined high and low dairy land and population expansion scenarios with estimates of future trends in animal productivity and fertilizer use to construct two fundamental scenarios: 'dairy expansion' and 'constrained dairy expansion'. Building on those, we constructed two key baseline scenarios: a 'maximum efficiency' scenario, which uses animal numbers from the 'dairy expansion' scenario, but with further increased milk yield of dairy cows and higher assumed liveweight gain in growing beef and lambs; and a 'minimum efficiency' scenario that uses animal numbers from the 'constrained dairy expansion' scenario, but with increased weights of breeding females and lowered growth in milk yield of dairy cows while maintaining rates of growth in growing animals.

The baseline scenarios do not include any potential constraints on future growth that could arise from concerns about water quality and related nitrogen limits, or irrigation. These issues could have a significant impact especially for the dairy sector, but insufficient information was available to include this in our scenarios.

A range of mitigation actions were applied to the maximum and minimum efficiency baseline scenarios, including amended nitrogen content of animal diets, reduced fertiliser use, breeding and selection for low-emitting cattle and sheep, vaccines, inhibitors and changed manure management practices. We emphasise that our mitigation scenarios do *not* include policies or regulations that would imply significant additional constraints on land, stocking densities or nitrogen loading, or policies that would shift the profitability of different types of land-use through imposition of a cost of carbon on agriculture. Thus, the analysis in our report is limited to mitigation options that do not constrain the total amount of livestock production relative to baseline scenarios, and the only changes considered relate to the balance between livestock species and the intensity of production systems, including use of specific management practices and technologies.

Based on the individual mitigation options, combined packages of mitigation outcomes (both on an absolute emissions and emissions intensity level) are presented, including the influence of the choice of base year (or base period) and different levels of adoption of new technologies for different sub-sectors (dairy, sheep and beef).

Insights from baseline scenarios for emissions targets

<u>Absolute emissions</u>

- Under all baseline scenarios, absolute emissions from agriculture will continue to increase. Depending on baseline trends, emissions in 2030 would be 7.6-9.9 Mt above 1990 levels and 4.1-6.4 Mt above average 2008-2012 levels. These equate to percentage increases of 22-29% and 11-17%, respectively.

- Absolute emission estimates in our baseline scenarios already incorporate increases in the efficiency of production in line with historical trends. These already reduce emissions relative to a hypothetical case where production increases in future but efficiency remains the same; such underlying efficiency improvements are in essence 'business as usual' and we would expect them to occur in the absence of any climate driven interventions.

Emissions intensity

- Emissions intensity will continue to decline even in the absence of climate policies, but maintaining historical rates of decline linearly into the future appears very unlikely based on market drivers alone, even if historical rates of increasing production efficiency are maintained. This is due to the inevitable fall-off as production per animal rises.
- The historical decline between 1990 and 2012 is 1.0% per annum (relative to the mean emissions intensity for this period); this falls to 0.3 to 0.6% for the period 2015-2030, and to 0.3 to 0.5% for the period 2030-2050 in our baseline scenarios.
- Rates of decline in the beef sector could remain relatively close to historical rates, but this is mainly an artefact of the expansion of the dairy sector and the apportioning of emissions strictly by sector rather than product.

The large historical multi-year variability in emissions (both absolute and intensity) means that future targets and baseline values should be based on multi-year averages or modelled reference values rather than selected individual year values. Emissions intensity tends to be more variable year-to-year, reflecting farm-level management decisions in response to price expectations and climate conditions; absolute emissions also show variability but typically over slightly longer time frames of several years.

Impact of mitigation options

Low/no-cost mitigation options: low-nitrogen feed, more efficient use of nitrogen fertiliser, and accelerated performance

Effect on absolute emissions

- Introduction of low N feeds and increased efficiency of N fertiliser use result in reductions of 3.4-3.7% by 2030 and 6.5-7.2% by 2050 (assumed here to be feasible without affecting total production).
- Accelerated individual performance over and above the efficiency gains already assumed in the baselines increases emissions; by 2.6-4.3% in 2030 and 3.3-8.1% in 2050 for the minimum and maximum efficiency scenarios respectively. In our scenarios, this acceleration occurs without any restriction on animal product or feedback on animal populations (or constraints from water quality implications)

Effect on emissions intensity

- All of these actions result in a fall in emissions intensity, over and above the fall that already occurs in the baselines; their additive effect ranges from 2.9-5.6% by 2030 and 7.1-11.2% by 2050.

Low-cost but unproven or not-yet commercialised options: vaccines, Inhibitors and low-methane emitting animals

Effect on absolute emissions

- Individually and collectively these options can have a significant effect; they are estimated to provide more than half of the total abatement potential even if their adoption remains relatively limited by 2030. For the methane vaccine and inhibitor, the amount of abatement per animal is speculative at this stage; we have assumed values based on our expert judgement and existing trials.
- The amount of mitigation, particularly for the methane vaccine/inhibitor, depends not only on the abatement per animal but also critically on the assumed rate of adoption.
- With high rates of adoption (and in conjunction with other mitigation measures considered in this report), emissions could be below average 2008-2012 levels by 2030, and even approach 1990 levels if the expansion of dairy is limited.

Effect on emissions intensity

- As for absolute emissions, individually and collectively these options can have a significant effect and would provide approximately between a third and a half of the total abatement.
- The same caveats regarding the amount of abatement per animal, and the rate of adoption, apply as for absolute emissions.
- With low rates of adoption, the rate of decline in overall emissions intensity would still not achieve a linear continuation of the 1990-2012 average rate of decline. Only with high rates of adoption, and when combined with other mitigation options considered in this report, the rate of decline in emissions intensity could approach and even exceed the historical level of 1%.

High-cost mitigation options: DCD, modified manure management with CH_4 capture

- Despite high efficacy, the effect of DCD is minor on both absolute emissions and emissions intensity due to assumed restricted applicability. Its cost per avoided emission is high. However, drivers for its uptake could arise from non-climate policies related to water quality; our scenario analysis suggests that as its effectiveness is currently restricted by soil temperature, even an uptake by 100% of all dairy farms would still have only a moderate effect (in the order of 2% of total emissions from agriculture in 2030).
- Increasing the proportion of animal wastes treated in anaerobic ponds has a minor impact on absolute and emissions and emissions intensity, even when additional CH_4 emissions are 'captured', because emissions of N_2O still arise from spread manure. If CH_4 arising from anaerobic ponds is not fully captured, net emissions would increase rather than decrease from this option.

Implications for emissions targets

Setting emissions targets will inevitably require political judgements. The aim of this report is not to influence such judgements, but to provide information that can support the decision-making process. We reiterate that the mitigation options and outcomes presented in this report rely on a range of assumptions, and have excluded policy options that would negatively affect the economic growth aspirations of the agriculture sector.

Absolute emissions

- Absolute emissions from agriculture will continue to rise, making any reduction target below 1990 or 2008-2012 levels highly challenging and, based on current knowledge,

impossible unless the expansion of the agricultural sector itself were constrained or new, highly efficacious mitigation technologies successfully developed and adopted widely.
- With high rates of adoption, it is possible that absolute emissions could fall below average 2008-2012 levels if all mitigation options considered in this report are indeed available and fully effective. However, even for a low-emissions baseline, the most ambitious mitigation package still does not manage to reduce emissions to 1990 levels in 2030 or beyond.
- The success or failure of the development of a methane vaccine/inhibitor has a large influence on the achievable emission target.

Emissions intensity

- Emissions intensity might appear as a more attractive metric to characterise progress as ‘emissions’ are seen to fall continuously even in the absence of climate policies. Hence any realistic future target would (and should) be expressed as significant further reduction compared to 1990 or average 2008-2012 levels.
- With mitigation, it may be possible that historical rates of emissions intensity reduction can be maintained or exceeded dependent upon uptake. However, large increases in the rate of reduction of emissions intensity appear difficult, in part due to the expected declining rate of improvement in baseline scenarios.
- Since emission intensities will fall simply due to the general baseline improvements in efficiency, any target that represents climate-related efforts would need to be set below these ‘natural’ rates of decline. Our maximum base case could perhaps be considered as setting a minimal level of expected achievement.
- In our scenarios it should be noted that there is an inherent contradiction with regard to targets: without additional mitigation, the maximum efficiency scenario results in the lowest emissions intensity but the highest absolute emissions.

Obtaining the largest reductions in absolute emissions, and/or achieving reductions in emissions intensities that approach or exceed historical rates, relies on the availability and adoption of new mitigation technologies. This applies to any ambitious target, regardless of whether such a target is stated in terms of absolute emissions or emission intensity.

Targets expressed as absolute emissions or emissions intensity are interchangeable in respect of the actual mitigation actions, productivity, and general assumptions that they rely on. An emissions intensity target thus does not in itself imply a higher or lower level of commitment; it is the amount by which a target is below baseline that determines its stringency, not the way it is expressed. The main difference between an intensity and absolute target is that the former appears less prone to changes in international market conditions or domestic non-climate policy settings, and thus would appear less likely to generate either ‘hot air’ or result in an overly stringent commitment. On the other hand, an absolute target more directly focuses on the driver of climate change, which is the absolute amount of greenhouse gas emissions to the atmosphere.

Purpose

This report has been commissioned by the Ministry for Primary Industries (MPI) to provide information on expected future agricultural emissions and the potential of mitigation actions. It aims to assist in developing different approaches to an agricultural target as part of New Zealand's contribution to a post-2020 agreement under the UNFCCC.

The report provides emissions data obtained from a range of emissions scenarios (baselines and targeted mitigation actions to reduce absolute emissions and/or emissions intensities relative to baselines) through until the year 2050, with a specific focus on 2030. Scenario analysis has been used to explore the consequences of different approaches for emission trends.

This report considers mitigation options consisting of various ways of improving farm efficiency alongside those that rely on the implementation of new technologies. The mitigation scenarios do *not* include policies or regulations that would imply significant additional constraints on land, stocking densities or nitrogen loading, or policies that would shift the profitability of different types of land-use through imposition of a cost of carbon on agriculture. Modelling the effects of such policies would require the use of economic tools and would rely on policy assumptions outside the scope of this report.

Changing global market conditions could also have a major impact on agricultural production and emissions in New Zealand, but the characterisation of future global markets, let alone quantification of their implications for New Zealand livestock production and emissions, was beyond the scope of this report.

Related to the above exclusions, the report did not investigate potential changes in total available agricultural land and the level of use of agricultural land between ruminant livestock and production forest, horticulture or arable crops. In other words, a basic assumption of the report is that agricultural land currently in ruminant livestock production will remain in some form of ruminant livestock production, and the only changes considered relate to the balance of livestock species and intensity of production systems, including use of specific management practices and technologies. While this assumption of a static total land area for livestock production is unlikely to remain the case in reality over the next several decades, it is beyond the scope of this report to assess potential changes in land use.

Based on the individual mitigation options considered in this report, a combined package of mitigation outcomes (both on an absolute emissions and emissions intensity level) is presented, including the influence of the choice of base year (or base period) and metrics to aggregate emissions intensities from different sub-sectors (dairy, sheep and beef). The report does not make any recommendations on suitable or desirable targets, but seeks to inform political decisions about such targets by presenting the influence of different measures on emissions and providing a high-level indication of economic, environmental and social aspects relating to their implementation in a New Zealand context.

1. Approach

This report uses New Zealand's national greenhouse gas emissions inventory and reporting tool as the primary vehicle to estimate emissions and the effectiveness of different mitigation options. This ensures that any actions taken could in fact be reflected in the national inventory and hence could be used to support any commitments by New Zealand. It does imply some limitations, however, as the inventory in the form it was available for this report only operates at a national scale, and hence sub-national variations or regionally different actions had to be estimated and aggregated up to a national level; this could hide actions that could reduce emissions at regional or individual farm levels, but reporting such actions consistent with national reporting requirements would be challenging.

In all of the presented scenarios we have estimated national-level effects by implementing each mitigation measure in the inventory and reporting tool, on the assumption that such mitigation measures could be monitored, reported and verified to a standard required for formal reporting of emissions to the UNFCCC. We note in the report particular areas where improvements to the national inventory appear to be possible and desirable to better reflect potential mitigation actions.

We have restricted our choice of mitigation measures. For currently available technologies, we have only looked at the impact of those we feel have sufficient science evidence to back up claims of reduced emissions; the best example is DCD. For existing technologies this approach ruled out things such as brassicas that have well documented methane impacts but poor information on their impact on nitrous oxide emissions, which could increase based on the limited evidence available. With regard to technologies that are not yet available, for example vaccines and inhibitors, we have used values which are realistic based on available evidence given the type of technology or, if this is not known, a value which is the minimum reduction needed for the technology to be regarded as being viable.

Emissions are generally reported as CO_2-equivalent emissions, based on 100-year Global Warming Potential (GWP_{100}) conversion factors as reported by the IPCC in its 4th Assessment Report and used in reporting emissions to the UNFCCC from 2013 onwards. Information about individual gases and the implications of alternative metrics to aggregate different greenhouse gases is provided in selected places where this was considered most relevant.

Emissions methodology is based on the methodology as used in the 2014 annual greenhouse gas inventory submission, which uses the 2000 Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, and the *revised* 1996 IPCC Guidelines for National Greenhouse Gas Inventories. From 2015 all parties including NZ will be reporting using the 2006 IPCC Guideline and revised reporting requirements adopted through decision 24/CP.19 (UNFCCC). The IPCC 2006 guidelines and decision 24/CP.19 introduce new categories of emissions from agriculture (e.g. CO_2 from carbon contained in fertiliser). These projections do not use the new guidelines or categories. As far as they could be evaluated, with the notable exception of a change in GWP factors for CH_4 and N_2O, revisions based on the 2006 guidelines result in relatively minor changes in overall emissions and opportunities for mitigation (this report uses the updated GWPs consistent with reporting from 2015 onwards). A much bigger change in reported emissions could arise from future revisions of emission factors, for example from nitrous oxide from animal excreta deposited directly onto pastures and from pasture deposited animal excreta in hill country (which is work currently in progress); however, as no agreed values are available yet we have not evaluated the impact of potential changes in emission factors on baseline and mitigation scenario emissions in this report. Even though such changes could have a material impact on reported absolute emissions, they are unlikely to change the broad picture of emission trends and the relative scale of impact from different mitigation options.

The scenarios developed in this report exclude energy, waste and transport emissions related to agricultural supply chains, but order-of-magnitude estimates are provided where relevant to highlight potential risks of pollution swapping (either between sectors, or between New Zealand and the rest of the world) where they could arise in mitigation approaches.

2. Production and productivity baseline scenarios

We analysed the existing New Zealand baseline emissions scenario used in New Zealand's most recent (6th) National Communication (NC6) to the UNFCCC. The agricultural emissions projection from this report is developed using data on animal populations derived from the MPI Pastoral Supply Response Model (PSRM) supplemented by projections of individual animal performance based on historical trends. The PSRM model projects trends in animal populations and is primarily driven by commodity prices for agricultural products, current productivity trends, and the returns on agricultural land relative to returns in the forestry sector. The assumed economic circumstances of the agricultural industry have a significant impact on the emissions projections. We have been unable to clarify the exact assumptions in the PSRM regarding international commodity prices, or assumed carbon prices on afforestation or deforestation in New Zealand, but note that they could have significant implications on livestock production levels in New Zealand and thus warrant further clarification and exploration via scenario analyses to explore uncertainty ranges of long-term projections.

The emissions projections for the National Communication follow a programme of continual improvement. Studies, such as this one, that can identify short comings in the projections are part of this continual improvement. On analysing the projections for animal populations and productivity we identified a number of areas where we feel it is possible to improve the quality of the projection based on available sources of information on productivity trends, market requirements, and availability of and competition for land.

2.1 Animal Populations

We identified and implemented several changes to the existing NC6 emissions baseline. We found the change in sheep numbers to be likely a result of the lack of constraints to land use in the PSRM. Although some land will be lost to dairy, based on current dairy stocking rates this does not explain the reduction of sheep numbers projected in the NC6 emissions baseline scenario: short of leaving land unproductive, the only alternative use would be a large scale expansion of forestry. Such a change would not be likely in a business as usual scenario (however may be considered as a mitigation scenario if forestry is exposed to a significant carbon price).

Hence, for the purpose of constructing baseline scenarios for this report, we have amended the current government projection of a continued decline in sheep numbers and instead modelled sheep populations based on an estimate of the future agricultural land area that is available for sheep and beef once land lost to dairy is taken into account. This shows some trade-off with dairy at the high-quality end of land, but most of the sheep land is unaffected by assumptions around dairy expansion.

Assumptions about available land for dairy, and feasible stocking densities for this land, vary widely and are subject to important assumptions about the maximum possible nitrogen loading. In the absence of the availability of a detailed spatially disaggregated model, we construct two alternative scenarios to estimate future dairy cattle populations. One scenario is based on our estimate of the upper end of land considered suitable for conversion to dairying and stocking densities based on existing farm practice. The other scenario uses the same stocking rate but assumes that less land is converted to dairying. No account was taken in these baseline scenarios for policy that may constrain nitrogen loss from agriculture in response to concerns related to water quality. Such policy would have an impact on greenhouse gas emissions, but because such policy would likely be implemented on a catchment scale, it was beyond the scope of this report to quantify possible mitigation outcomes. However, we are acutely aware that the possible constraints on livestock production, particularly dairying, arising from water quality concerns could impact livestock populations and land use and this is an area that warrants a more detailed investigation. To provide context for such future work and indicate the scale of interactions, we present the national-level nitrogen leaching implied in various scenarios to indicate the scale of change implied in baseline scenarios (see section 2.3). We have also not taken into account the impact climate change itself could have on livestock populations and land use.

These two alternative dairy expansion scenarios affect the amount of land available for sheep and beef production, and also influence overall beef production via an increase in the number of culled dairy cattle. This latter factor does not influence beef cattle emissions but does affect the emissions intensity of beef (see later section). To derive beef and sheep populations in 2050, we multiplied current populations by a factor that was estimated from the proportional loss of beef and sheep land and current beef and sheep stocking rates estimated using livestock units; this was 0.8 for the upper land loss to dairy and 0.9 when less land was lost.

Using a land area approach to estimating future populations in the dairy, beef and sheep sectors is challenging, even when it is assumed that the total land area available for the sector is fixed. For example, using current stocking rate averages to estimate future populations may not be appropriate due to land use changes within the livestock sector as a whole due to the continued expansion of dairy. Interactions between sectors, in particular the beef and dairy sectors, also need to be taken into account as the increased supply of surplus dairy animals influences the make-up of the national beef herd; this latter issue is particularly difficult as trends within the sector (e.g. the decreased proportion of breeding beef cows) have to be captured alongside changes in the total number of animals based on the area of land available. Our population estimates are therefore subject to considerable uncertainty.

Table 1. Total animal populations in 1990 from the NC6 baseline and the two new baselines (million).

	NC6			High dairy expansion			Low dairy expansion		
	Dairy	Beef	Sheep	Dairy	Beef	Sheep	Dairy	Beef	Sheep
2012	6.17	3.85	31.1	6.17	3.85	31.1	6.17	3.85	31.1
2050	N/A	N/A	N/A	9.13	3.24	24.91	7.71	3.61	28.01

2.2 Individual Animal Productivity and nitrogen use

In addition to modifying some of the current NC6 baseline population projections we also modified some of the individual animal performance projections. The increase in milk production per cow from the current 4000 per cow to 4500 per cow by 2050 in the NC6 baseline seems very conservative given both the historical rate of increase and industry efforts to improve farm efficiency by stressing a better balance between individual animal performance and stocking rate. Conversely, we judged that the large projected increases in the weight of reproductive females in the sheep and beef cattle sector in NC6 was far too high. We feel that any large increase in the weight of reproductive females is unlikely, as increasing the weight of breeding females is inefficient due to their high maintenance cost; current breeding goals are to constrain these weights while expanding the growth rates of their offspring. We also felt that the predicted increase in lamb carcass weight was also too high, given that very large carcasses do not fit current market specifications and that increased prolificacy would put downward pressure on lamb carcass weights due to the increased number of lambs that need to be finished.

Fertiliser use in the NC6 baseline scenario is forecast to expand to from the current value of 362,000 tonnes to 676,000 tonnes. This seems a large increase given that water quality issues are likely to place considerable downward pressure on N fertiliser applications. In addition, the dairy sector is by far the largest user of fertiliser and even if numbers increase as per the NC6 baseline, it is hard to see how such a high figure can be justified as fertiliser use per animal peaked in 2005 and has fallen by about 18% since then. The total amount of fertiliser used has still increased since 2005, due mostly to dairy cattle numbers increasing by almost 1.5 million, but at a much slower rate than previously. We adopted an alternative approach and based our scenarios using fixed amounts per head of livestock for each sector, these fixed amounts being varied for the different scenarios.

2.3 Scenario Construction

We combined the high and low dairy land expansion population scenarios with our best estimates of future trends in animal productivity and fertilizer use to construct two fundamental baseline scenarios: 'dairy expansion' and 'constrained dairy expansion'. To take into account the uncertainties around future individual animal performance values we constructed two additional baseline scenarios: a 'maximum efficiency' scenario, which uses animal numbers from the 'dairy expansion' scenario but further increased the milk yield of dairy cows and assumed a higher liveweight gain in growing beef and lambs; and a 'minimum efficiency' scenario that uses animal numbers from the 'constrained dairy expansion' scenario but increased the weights of breeding females and lowered the growth in the milk yield of dairy cows while maintaining rates of growth in growing animals.

For internal consistency, the same efficiency assumptions are then also used to construct a full set of scenarios for sheep and beef production (i.e. the 'maximum efficiency' scenario assumes high efficiency in dairy as well as sheep and beef, whereas the 'minimum efficiency' scenario assumes lower efficiency gains across all three types of livestock).

Our Maximum Efficiency scenario assumes greater increases in individual animal performance for all animal classes with the same quantity of fertiliser per animal. The Dairy Expansion Scenario has lower animal performance gains at the same level of fertiliser use and the same populations as the Maximum Efficiency case. Differences between these two scenarios simply reflect a more optimistic rate of improvement in the efficiency of production. These scenarios could be considered likely if all land theoretically available for different livestock production systems is in fact used and farmers maximise production in a highly efficient manner, reflecting sufficiently high commodity prices and limited other constraints on livestock production/land from forestry or concerns about water quality or irrigation.

Given that higher efficiency achieved through increased performance per animal implies higher emission per animal, the 'maximum efficiency' scenario also represents the scenario with the highest absolute emissions.

The 'minimum efficiency' and the 'constrained dairy expansion' baseline scenarios have the same populations in each livestock species. For dairy these are lower than in the Maximum Efficiency and Dairy Expansion to reflect the lower amount of land devoted to dairying. Conversely sheep and beef numbers are higher, given the competition for land between dairy and sheep/beef. With regard to production per animal, the Constrained Dairy has high animal performance while the Minimum Efficiency has a slower increase in productivity indicators such as growth rates and milk yield per animal. The Minimum Efficiency simply reflects a more pessimistic view of improvements in efficiency. These scenarios could be considered likely under lower commodity prices and hence less intense land use, more limited use of irrigation, concerns about water quality as well as other factors.

Note that the Minimum Efficiency scenario does not equate to a scenario with minimum absolute emissions, because this scenario assumes lower efficiency gains due to increased weights of breeding stock with the weights of growing stock remaining constant.

In all scenarios wool production is included in the energy and nitrogen demand and retention for sheep meat production, but emissions related to wool production are not reported separately as their energy content is relatively small compared to the energy demand for meat. Only milk and beef/sheep meat production values are used when calculating emission intensity values.

Table 2. Dairy productivity values for the NC6 and four new base scenarios

	Milk Yield	Cow Weight
2012 base value	3972	463
Max Efficiency 2050	5500	470
Dairy Expansion and Dairy Constrained 2050	5000	470
Minimum Efficiency 2050	4500	470

Table 3. Beef cattle performance data for 2012 and 2050 for the NC6 and four new base scenarios (mature liveweight for Cow and slaughter weights (kgs) for the others)

	Steer	Heifer	Bull	Cow
2012 base value	307	234	303	531
Max Efficiency 2050	325	250	325	550
Dairy Expansion and Dairy Constrained 2050	315	240	315	550
Minimum Efficiency 2050	315	240	315	575

Table 4. Sheep performance data (kg) for 2012 and 2050 for the NC6 and four new base scenarios

	Ewe weight	Lamb carcass weight
2012 base value	57.7	17.6
Max Efficiency 2050	65	22.5
Dairy Expansion and Dairy Constrained 2050	65	20.25
Minimum Efficiency 2050	70	20.25

Table 5. Nitrogen fertiliser applications (tonnes per annum) for 2012 and 2050 for the NC6 and new base scenarios

	Total N use
2012 base value	362,000
Dairy Expansion & Maximum Efficiency 2050	481,000
Dairy Constrained & Minimum Efficiency 2050	418,000

A critical assumption in this report is that both population and individual performance parameters change linearly between now and 2050. This will not be the case in practice, particularly for population changes; detailed economic modelling may indicate non-linear trends, but also would be subject to assumptions about long-run developments in international dairy prices and market access for New Zealand. Undertaking such modelling (including assessment of assumptions and uncertainties relating to global market conditions, or policies for forestry in New Zealand) was outside the scope of this study. We note, however, and emphasise that this could be of major importance for New Zealand, particularly since the shape of population trends within and between sectors could considerably affect projected baseline emissions in 2030.

Our two baseline scenarios thus differ mainly with regard to domestic non-climate policy settings and operating conditions, but assume similar international settings and domestic climate and water policy settings (i.e. continued high demand for milk products, no significant differences in the pressure that forestry could exert on low-value agricultural land, or the constraints that nitrogen limits could exert on overall stocking densities in individual catchments). Significant changes in international market settings could markedly change the emissions trajectories presented here and the range between high and low scenarios. This is of relevance if a 'reference level' type approach was used. However, in the absence of robust and credible alternative scenarios of global commodity price developments and market access for New Zealand (and appropriate tools to reflect the impact of such conditions on New Zealand's long-run production levels) we have been unable to account for those in our baseline scenarios.

Our approach to changes in individual animal performance are changing milk yield per animal and milk quality, and increased weights at slaughter in the beef and sheep sectors. However, these are not the only way in which performance can be changed; for example slaughter weights could remain constant but the time taken to achieve these weights could be varied. The inventory and reporting tool currently incorporates fixed slaughter dates and we did not make any attempt to vary these. As assuming higher weights and a fixed slaughter date already incorporates increased growth rates per animal we do not think that independently changing slaughter date will have a significant effect, but it is something that needs to be explored further.

Figure 1 compares the baseline emissions and animal populations in the NC6 and revised maximum and minimum efficiency baseline scenarios developed in this report.

Figure 1 also shows the total nitrogen leached under the NC6, maximum and minimum efficiency baseline scenarios. These data give an indication of the potential scale of implications for water quality and the importance of linking water policy with climate policy in the derivation of realistic baselines and mitigation targets. As discussed earlier, progressing understanding of those links and policy options would appear to be a high priority but requires spatially explicit modelling at the catchment scale and hence was outside the scope of this report.

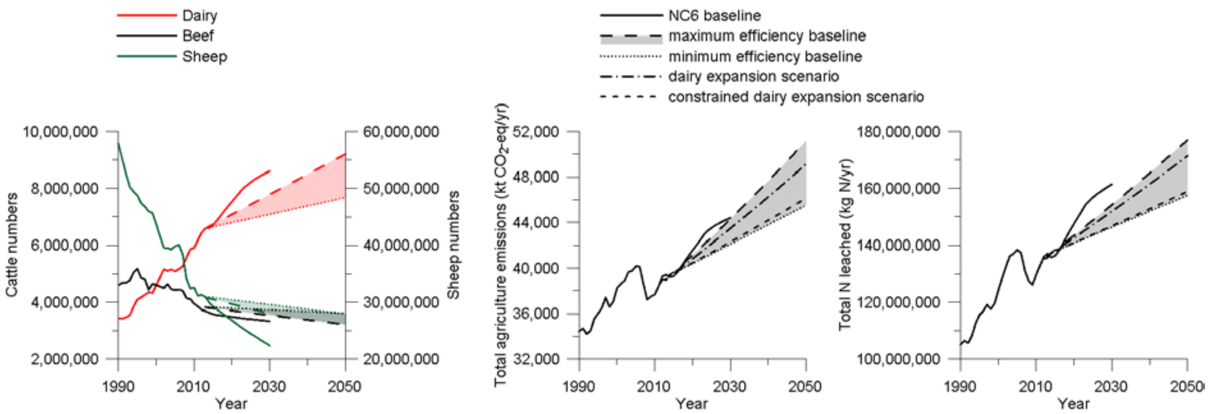

Figure 1. Comparison of animal populations (left panel), total emissions (middle panel) and total nitrogen leached (right panel) in NC6 and revised maximum and minimum efficiency baseline scenarios. Note that implications for water quality will vary from catchment to catchment, and total nitrogen leached as calculated by the inventory can only serve to indicate the potential scale of changes; it is not a suitable predictor for regional-scale changes in water quality.

3. Emissions under the four baseline scenarios

3.1 Absolute emissions

Total emissions from agriculture are estimated to be 34.5 Mt CO_2-eq/year in 1990 and 37.7 Mt CO_2-eq/year in 2010[1], with 97% coming from livestock farming. For the contrasting baseline assumptions developed in this report, estimated emissions in 2030 could range from 42.1 to 44.3 Mt CO_2-eq/year, and 45.5 to 51.2 Mt CO_2-eq/year in 2050. These emissions would correspond to 22 to 29% above 1990 levels in 2030 and 32 to 49% in 2050 (compared with 2012 emissions being 15% above 1990 levels).

We are unable to determine a ‘most likely’ scenario within these ranges, as the likelihood of any of those potential baseline scenarios depends on much broader economic trends, societal concerns and policy settings.

As noted above, estimated emissions by 2030 could depend markedly on the pace with which the dairy sector expands relative to its long-run potential. This can be seen clearly by the relatively large difference in animal numbers and associated emissions from the dairy sector in 2030 in the original NC6 baseline (see Figure 1). Our scenarios do not take account of such a potential non-linear expansion of the dairy sector and thus do not necessarily

[1] Note these values differ from those in New Zealand’s latest inventory reported to the UNFCCC, because this is still using the older GWP values, whereas we use the updated values that will be used for reporting of emissions from 2015 onwards.

encapsulate the full range of possibilities in 2020 or 2030. We note that a considerable part of the projected dairy expansion is likely to take place on land relying on the installation of irrigation, and some dairy expansion could be constrained by irrigation schemes approval processes.

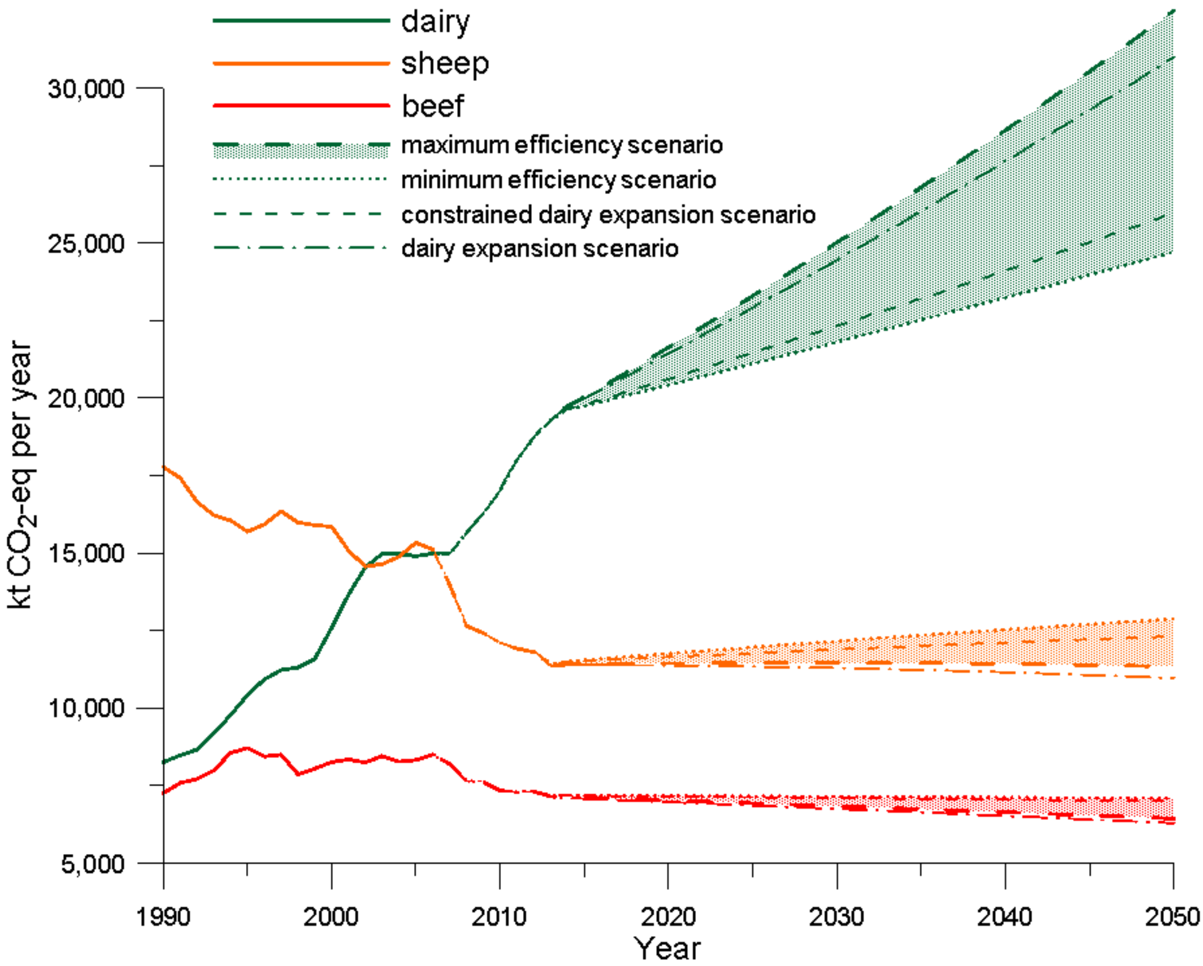

Figure 2. Absolute emissions from dairy, sheep and beef in baseline scenarios.

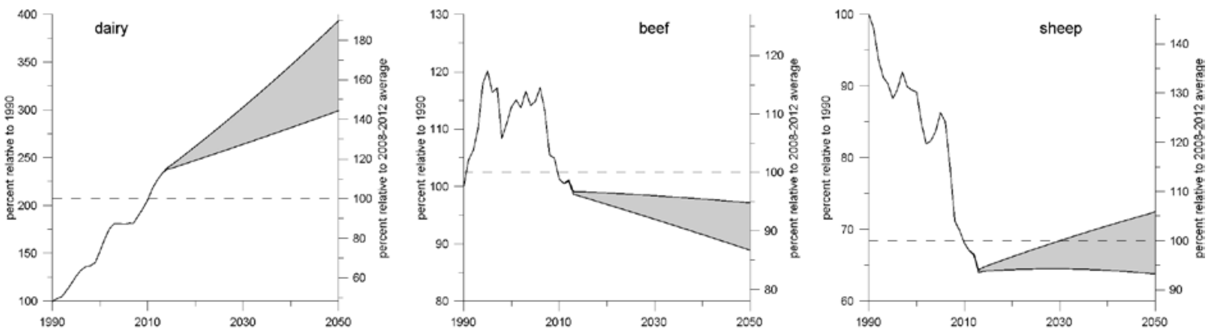

Figure 3. Percentage change in emissions from dairy, sheep and beef relative to 1990 and relative to the average of 2008-2012 in each sector, for the maximum and minimum efficiency scenarios.

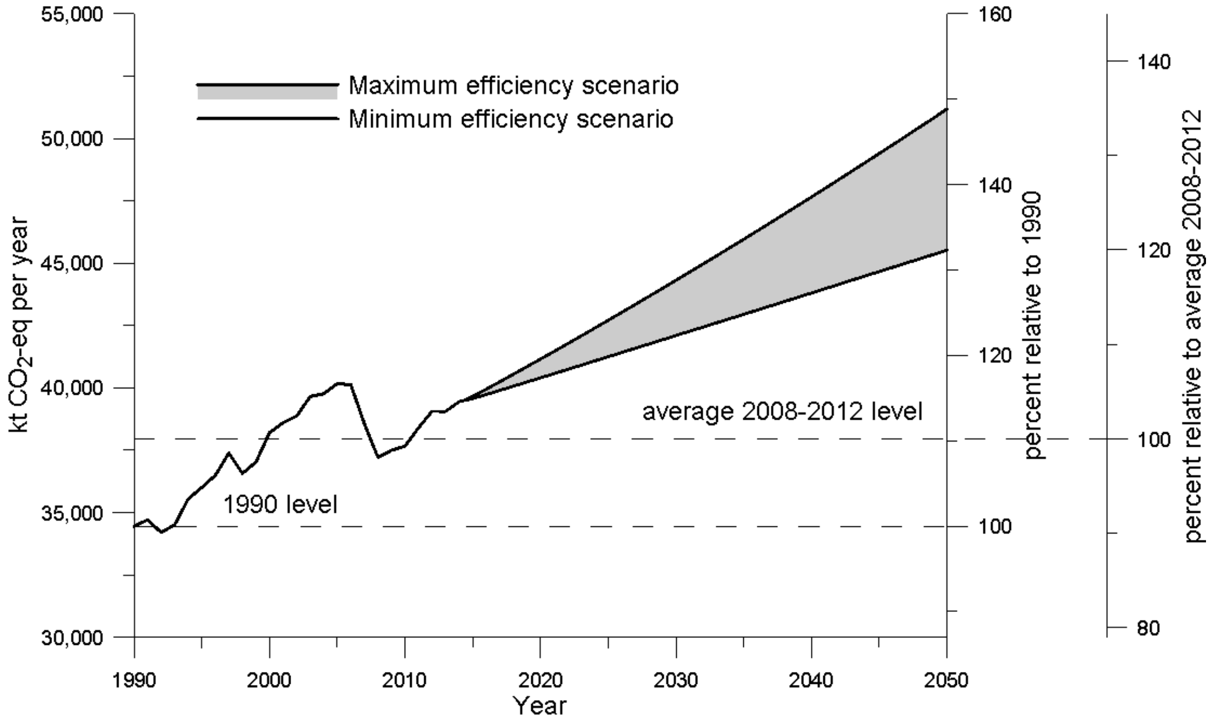

Figure 4. Absolute emissions for all agriculture sectors combined in baseline scenarios; right-hand axes show percentages relative to 1990 and relative to the average of 2008-2012.

Emission trends look similar for CH_4 and N_2O separately (shown in Figure 5), albeit with slightly different temporal evolution. From 1990 until the early 2000's emissions of N_2O from dairy rose more rapidly than CH_4 emissions, reflecting increasing emissions coming from the exponential increase in fertiliser use since 1990. These differences however have started to disappear since fertiliser use per animal peaked in 2005. As all of the baseline scenarios assume a constant N fertiliser use per animal in future, projected future N_2O and CH_4 emissions follow a very similar future trajectory.

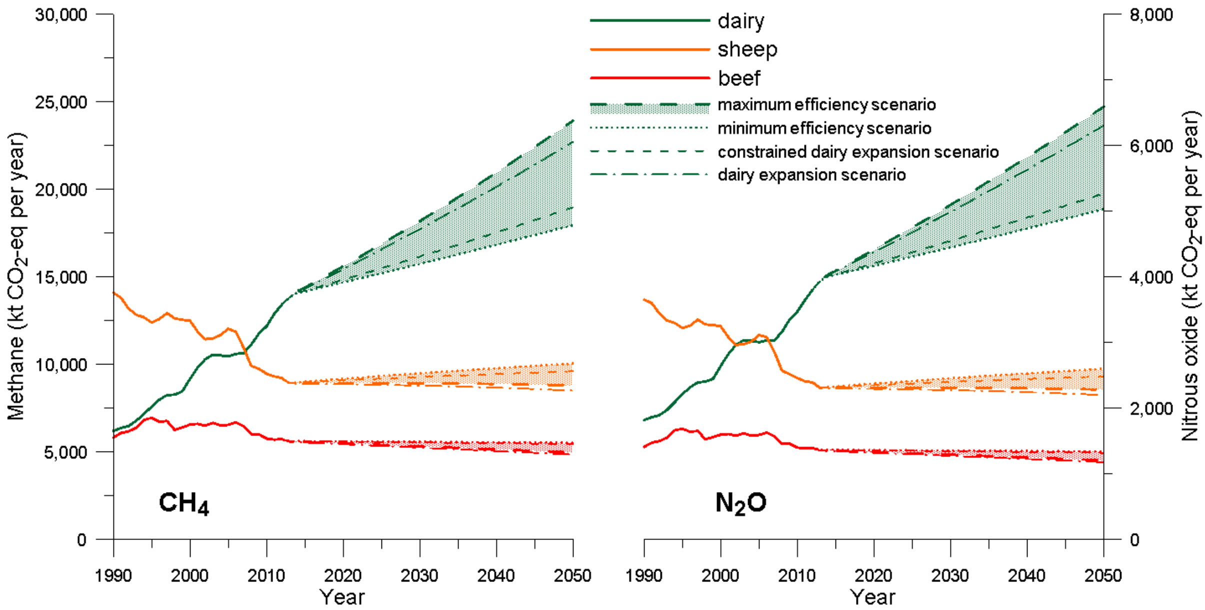

Figure 5. Absolute emissions from dairy, sheep and beef in baseline scenarios, separated for CH_4 (left) and N_2O (right).

3.2 Emissions intensities

A priori we would expect to see a gradual reduction in the rate at which emission intensities decline albeit over different time frames for different livestock systems. The reasons for this are twofold: one is the fundamental relationship between productivity (yield per animal) and emissions intensity, and the second is increasing challenges to maintain historical rates of increases in yields, given market demands, farm practice and in some cases animal physiology. These fundamental relationships can often be hidden when intensities are looked at over short time frames and when there is considerable year to year variability due to exogenous factors; linear relationships often providing an equally plausible fit to data over shorter time periods as non-linear fits.

3.2.1 Fundamental relationship between emissions intensity and yields

Total emissions from livestock production in general consist of two components: emissions related to maintenance of the animal, and emissions related to the actual production of the goods the animal is kept for (i.e. milk, or weight gain for meat; wool constitutes only a small percentage of the energy required by sheep and is not considered separately in the remainder of this report).

Because of this fundamental relationship, the emissions intensity of livestock production necessarily follows a non-linear, asymptotic shape: as production increases, the relative contribution of maintenance emissions decreases relative to production-related emissions. In an extreme case of a very highly productive individual, where almost all emissions arise from the production of meat/milk and animal maintenance becomes negligible, further increasing the amount of production per animal will result in only minor further reductions in emissions intensity. As a result of this basic functional relationship, *linear increases in farm level productivity (e.g. a linear increase in milk yield per cow every year) will not result in a linear decline in emissions intensity*, but in a gradually declining reduction in emissions intensity over time. This relationship is shown schematically in Figure 6.

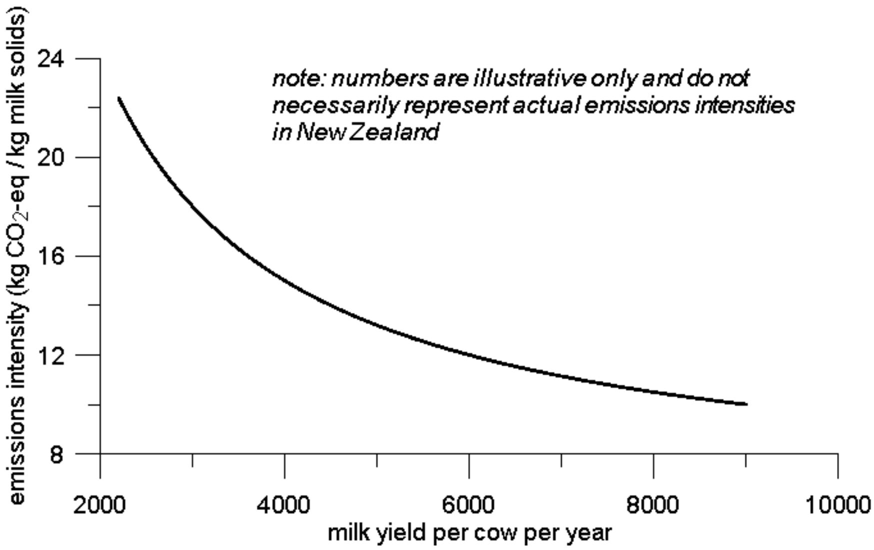

Figure 6. Indicative relationship between emissions intensity (i.e. total emissions related to animal maintenance and animal production divided by total production) and total production per animal.

Deviations from this basic functional relationship are of course possible if production systems are changed to achieve increasing levels of individual animal performance.

Fundamental changes are unlikely in New Zealand in the sheep sector, although they are possible in the dairy sector where in the long run there could be a shift from grazing-based to housed dairy operations with intensive feed supplementation in some areas. Such fundamental, large-scale system changes have not been considered in this report as information about their feasibility, cost and acceptability were not available to the authors.

A key conclusion from this fundamental perspective is that *even if* the linear trends in factors that have driven historical reductions in emissions intensity can be maintained (such as increased lambing percentages, weight gain of lambs until slaughter, milk yield per cow, and weight gain of finishing beef cattle), this will not result in a linear reduction in emissions intensity, but in a gradual slowing and flattening out of this trend.

3.2.2 Limitations from farm practice and animal physiology

Additional constraints to improving performance per animal come in part from market demands (e.g. while lamb slaughter weights have been increasing and have resulted in lower emissions per kg of lamb meat, there may be limits to how heavy lambs can be and still meet market expectations) and in part from farm practice and animal physiology (e.g. while breeding ewes and beef cows have become heavier over time, there is now active selection against further increases in body weight due to energetic 'overhead' cost this incurs).

There is no indication that New Zealand production systems are approaching biological limits to production efficiency. For example, milk yields remain far below those already common in intensive systems in Europe or the US (which can be greater than 10,000 litres per cow per year, compared to about 4,000 currently in New Zealand), and average lambing percentages achieved in New Zealand are close to 130%, well below the genetic potential. Although biological limits are unlikely to be a barrier to improved individual animal performance, achieving such continued improvements in practice may be challenging as this goes beyond genetic factors. Therefore, forecasting actual rates of change is inherently difficult as they will depend on the operating environment for New Zealand farms (including labour supply, industry bodies, and access to finance) and international market expectations. The projections made in this report are thus inherently uncertain even though based on the best available information, including historical rates of change, animal physiology, market requirements and net economic returns for farmers.

The emissions intensity trends developed in this report and shown below include a range of assumptions about how lambing percentages, weight gain of lambs and finishing beef cattle, and milk yield per dairy cow will continue to change over time. In both our maximum and minimum efficiency baseline scenarios, the above productivity indicators continue to increase, but at different rates. This reflects a range of possible outcomes but does not necessarily include the absolute maximum and minimum. We also include a specific mitigation option (see Section 4) that quantifies the additional reductions in estimated emissions intensity that could arise from accelerated improvements in individual animal performance and farm management practices beyond those envisaged in the baselines.

We have not attempted for this report to back-cast emissions intensities prior to 1990, as data limitations make such estimates increasingly difficult, especially given the complex data requirement of the national emissions inventory. However, both for robustness of projections and for the purpose of communicating the importance of these findings to a wider audience, better quantification of emissions intensity trends prior to 1990, and understanding the relative importance of particular aspects of production efficiencies, would constitute useful future work.

3.2.3 Emissions intensity trends for sub-sectors under baseline scenarios

Emissions intensities are projected to continue to decline in both baseline scenarios for all livestock systems, reflecting continued improvements to on-farm efficiency achieved via improved individual animal productivity. Emissions intensities also declined in the original NC6 baseline.

Productivity per animal differs only for dairy and sheep in the Maximum Efficiency and Minimum Efficiency baseline scenarios. The Minimum Efficiency scenario has highest emissions intensity due to assumed lower animal performance, while the Maximum Efficiency scenario has lowest emissions intensity due to the higher assumed animal performance. Despite large differences in absolute emissions, the Dairy Expansion and Dairy Constrained have the same emissions intensities due to having the same animal performance assumptions.

Emissions intensities in the beef sector are heavily influenced by the contribution from surplus dairy animals to total beef production. Some of the beef production comes from culled dairy cattle and many finishing beef animals are the offspring of dairy cows. Using an approach in which emissions are delineated by production sector rather than product type means that the emissions from growing and maintaining culled dairy cows, plus the gestation requirements of the surplus calves that are subsequently reared in the beef sector, are counted towards dairy rather than beef emissions. This is consistent with the approach used in the inventory. Alternative approaches to allocate emissions exist, as used for example by life-cycle assessment methodologies, but have not been explored in detail in this report which is based on the use of the inventory reporting tool. Different approaches could be more relevant when designing sector-specific policies.

The implication of allocating all emissions from dairy cattle to milk production is that increasing dairy numbers will result in an apparent decline in the emissions intensity of beef, even if beef cattle do not change in either number or performance as more beef is produced from an increased number of culled dairy cows. In addition, the New Zealand beef industry sources growing stock from both beef breeding cows and from surplus stock from the dairy industry. As the emissions from the beef breeding cows are counted towards beef emissions, while the emissions from breeding dairy cows are counted towards the dairy industry, increasing the percentage of rising stock sourced from the dairy industry is a possible mitigation avenue for the beef industry and one that is already happening since the proportion of breeding cows in the national beef herd has declined steadily since 1990.This phenomenon is incorporated in the baseline scenarios.

Figure 7 to Figure 9 show baseline (historical and projected) emissions intensities for dairy, beef and sheep, based on the above assumptions and allocations of emissions. The baselines also show fitted non-linear trends, reflecting the expected long-term decline in the rate of improvement of emissions intensity based on fundamental principles (see 3.2.1) and practical reasons (see 3.2.2). Note that for shorter periods of time in a situation where populations and levels of production are subject to multiple influences, in particular for the historical period 1990-2012, linear trends can be fitted to the observed data with similar robustness – a period of two decades is not long enough to determine whether observed trends are still linear or have begun to flatten out. However, we emphasise that based on fundamental principles (see 3.2.1), linear trends are less likely to continue into the future than non-linear trends, even if such non-linear trends are not yet clearly evident in the historical data given the relatively large year-to-year variation in production statistics.

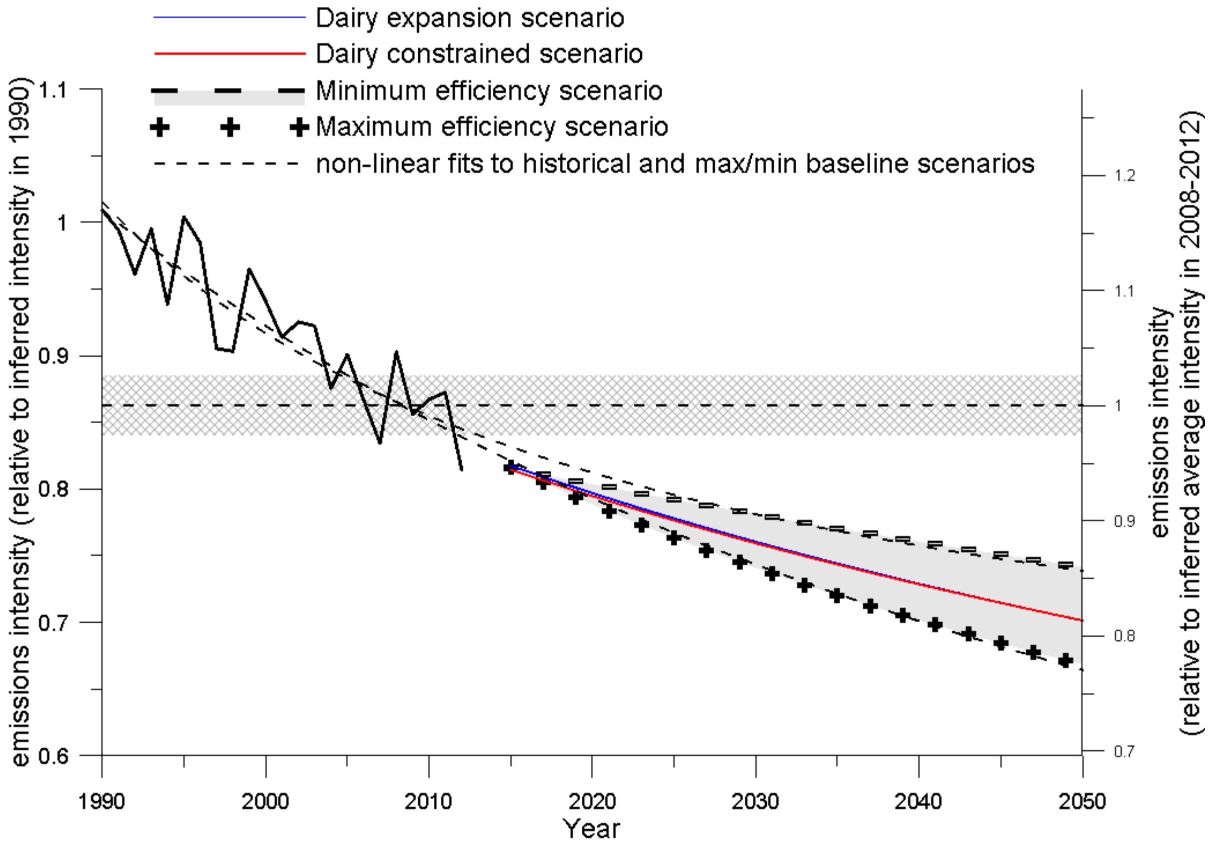

Figure 7. Historical and projected trends in emissions intensities for dairy. Emissions intensity was calculated as total emissions from all dairy animals (including calves that may be used for beef production) divided by total milk solids produced at the farm gate. The right hand axis indicates the change relative to the inferred average intensity over 2008-2012, and the grey shaded band indicates one standard deviation of this average based on historical data.

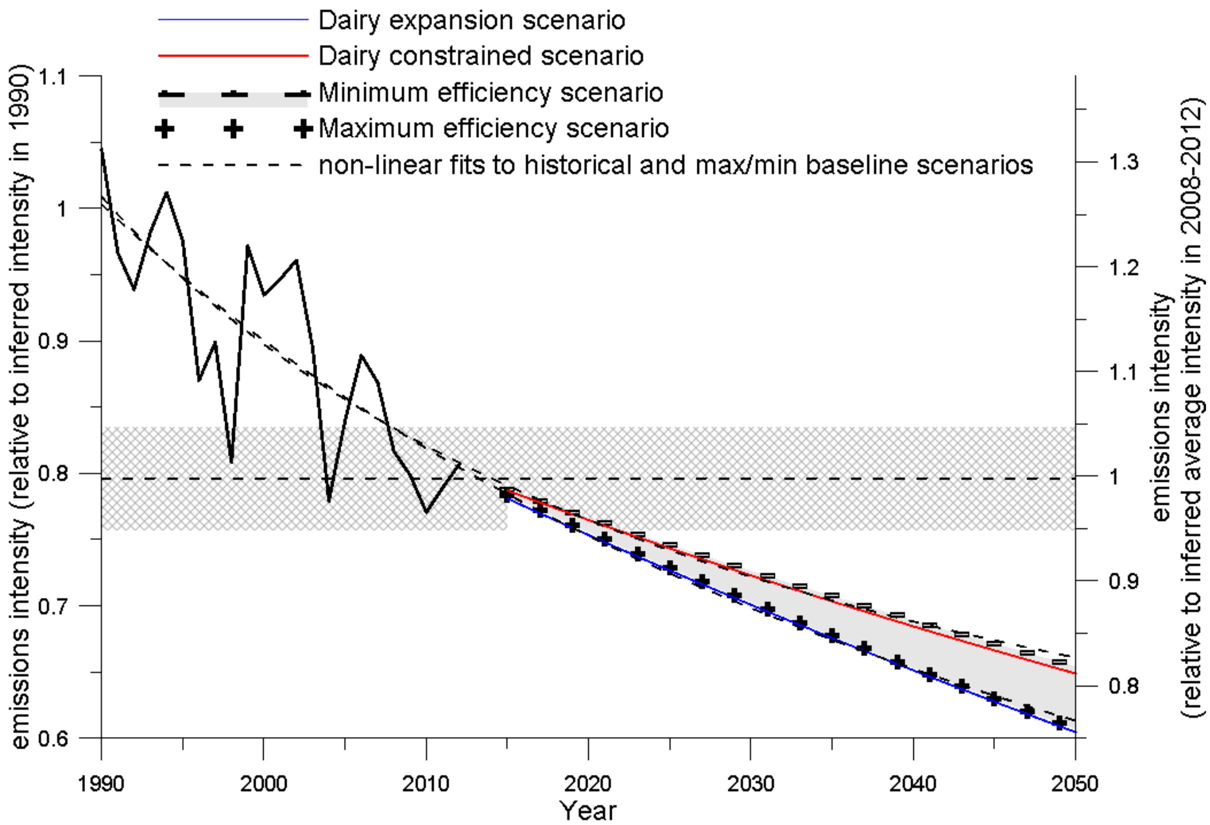

Figure 8. Historical and projected trends in emissions intensities for beef. Emissions intensity was calculated as total emissions from beef animals (i.e. excluding calves produced by dairy cattle) divided by total beef produced. The right hand axis indicates the change relative to the inferred average intensity over 2008-2012, and the grey shaded band indicates one standard deviation of this average based on historical data.

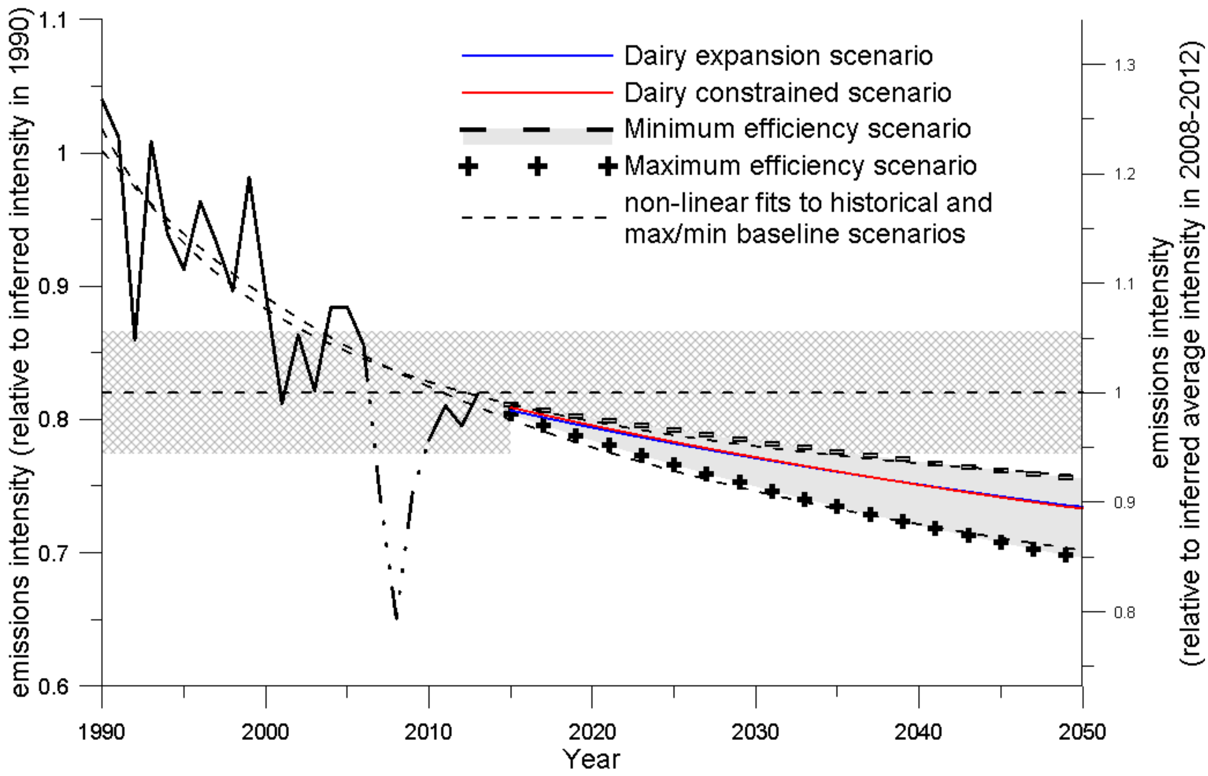

Figure 9. Historical and projected trends in emissions intensities for sheep meat (total lamb and ewe slaughter). Note that the calculation of emission intensity trends for sheep, intensities for the years 2007-2009 were excluded, because these years had very high drought-induced slaughter rates that skews the longer term trend towards lower values. The right hand axis indicates the change relative to the inferred average intensity over 2006 and 2010-2012 (i.e. with drought years excluded), and the grey shaded band indicates one standard deviation of this average based on historical data.

3.3 General trends in emission intensities

As discussed above, linear trends can be fitted to observed changes in emissions intensities with similar robustness of fit as non-linear trends over limited periods of time. Making this assumption of linearity for the period 1990-2012, emissions intensities declined by 0.8, 1.1 and 1.0% for dairy, beef and sheep, respectively based on emissions per litres of fat and protein corrected milk, beef (growing animals plus cull beef and dairy cows) and total sheep meat slaughtered (lambs plus cull ewes).

These trends are based on a fixed apportionment of fertiliser emissions of 75% to dairy, 10% to beef 10% to sheep and 5% to other sectors (consideration of which was out of scope for this report), and counting all emission from dairy cattle towards dairy even though some of those emissions are incurred in support of beef production. These values may differ somewhat from emissions intensity values reported elsewhere; main reasons for differences are different accounts of milk production (i.e. whether emissions intensity is relative to raw milk, or fat and protein corrected milk/milk solids produced, or milk solids processed) and whether and how fertiliser emissions are apportioned to different livestock systems. However, the trends are consistent with other reports.

The overall trend in emissions intensity of livestock production in New Zealand (if individual livestock intensities are weighted by their contributions to total emissions in each year) over the 1990-2012 period is -1.0% per year (relative to the mean emissions intensity over the 1990-2012 period). Other weighting methods to derive an overall emissions intensity for

New Zealand livestock production (such as contribution from each species to agricultural GDP, or to total protein produced) were not explored given the relative similarity in trends from individual sectors – hence only minor differences in the overall historical trend would be expected under different weightings.

As noted above, there are fundamental reasons why we would not expect the historical rate of improvement in emissions intensities to continue at the same rate into the future *even if improvements in production efficiencies continue at historical rates*. These changes in trends are summarised in Table 6 and Figure 10. For the period 2015-2030, the annual linear rate of decline in emissions intensities is expected to slow to rates of 0.3-0.6% per year for dairy, 0.5-0.7% for beef and 0.2-0.5% for sheep, for the contrasting maximum and minimum efficiency baseline scenarios. In the period 2030-2050, the rate of decline in emissions intensity is projected to slow further, to between 0.3-0.5% for dairy, 0.5-0.7% for beef and 0.2-0.4% for sheep. The higher rate of improvement in emissions intensities of beef is to some extent an artefact of the inventory-based accounting of emissions, since an increasing number of beef meat comes from the growing dairy herd and emissions related to this beef production are counted under dairy, not beef.

Table 6. Summary of historical and projected baseline emission intensity trends (for the maximum and minimum efficiency scenarios), determined by linear fits for different time periods, relative to the mean emission intensity in the 1990-2012 historical period). Note that drought years (2007-2009) have been included, giving relatively low values for sheep and total emissions intensity trends for the historical period 1990-2012.

SECTOR	1990-2012	2015-2030	2030-2050
Dairy	-0.8%	-0.3 to -0.6%	-0.3 to -0.5%
Beef	-1.1%	-0.5 to -0.7%	-0.5 to -0.7%
Sheep	-1.3%	-0.2 to -0.5%	-0.2 to -0.4%
total	-1.0%	-0.3 to -0.6%	-0.3 to -0.5%

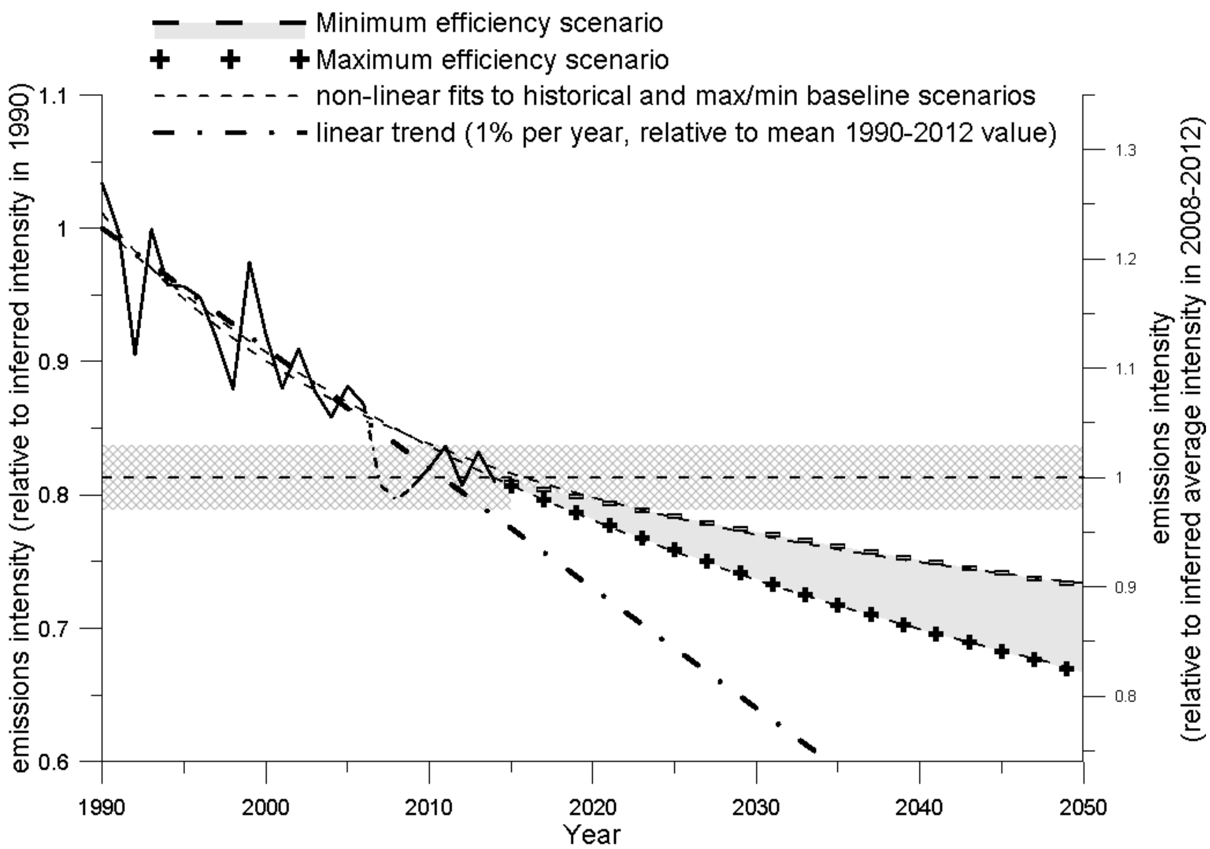

Figure 10. Emission intensity trends for agriculture as a whole, for two separate baseline scenarios, and with non-linear fits to the historical and projected future changes. Data for the period 2007-2009 have been excluded from the fits due to the drought resulting in artificially low emissions intensities for sheep due to high cull rates. Also shown is a linear trend of 1% decline per year, relative to the mean 1990-2012 emissions intensity (including drought-affected years).

Figure 11 shows emissions intensity trends for dairy separately for CH_4 and N_2O. In contrast to the overall emissions intensity trends, there is a marked variation over time in trends for the two separate gases, reflecting significant structural changes in the dairy sector. The period 1990-2012 saw a significant intensification with increasing reliance on fertiliser inputs, which resulted in a lower reduction of emissions intensity of N_2O over the 1990-2012 period (-0.1% per year, with a highly non-linear evolution over time) compared with CH_4 (-1.0% per year). Fertiliser use per animal peaked around 2004-2005 and has since declined by about 18%, resulting in a steep decline in emissions N_2O emissions intensity since that date. Going forward, as fertiliser use is becoming more targeted and the pasture-based diet is being supplemented, the emissions intensity of N_2O is projected to decrease more strongly and slightly exceeding the decline in emissions intensity of CH_4.

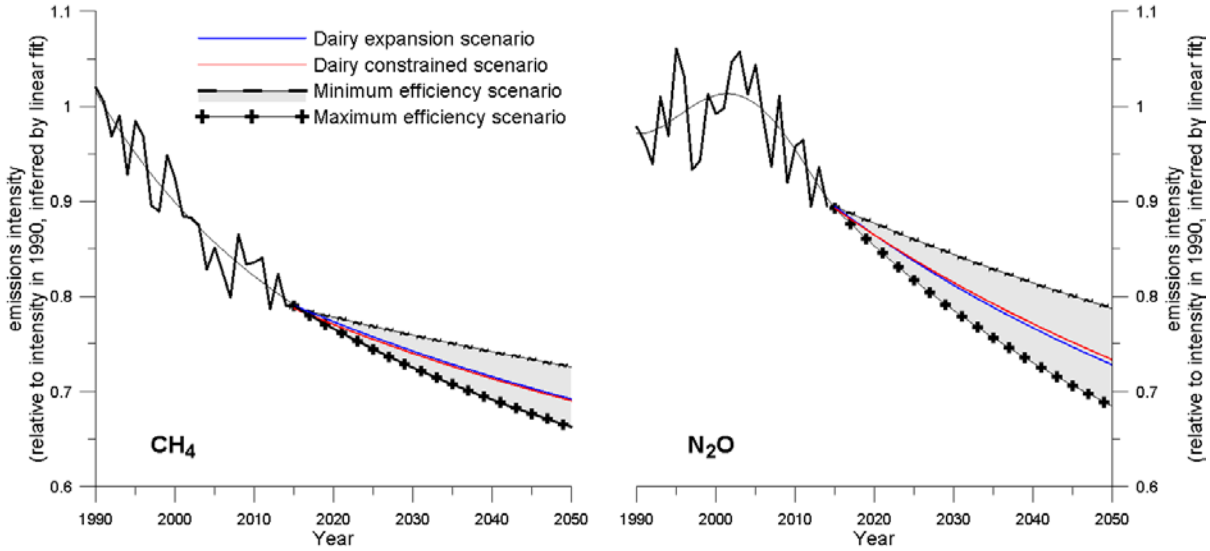

Figure 11. Historical and projected trends in emissions intensities for dairy, shown separately for CH_4 and N_2O. Thin lines indicate (non-linear) fits to the historical data, taking into account the projected future evolution of trends.

We note that there is a considerable inter-annual variability of emissions intensities. This is largely due to variable market conditions as well as between and within year climate variability. However, there is no clear correlation between drought years and apparent emissions intensity, because even though a drought would in principle reduce feed intake and productivity and hence increase emissions intensity, this can be offset either by increased use of purchased feed or by increased culling (hence the markedly lower apparent emissions intensity of sheep production in 2007-2009). The latter can then affect production in subsequent years and can also result in a cross-over between impacts of a drought on dairy and beef production (if an enhanced cull of surplus dairy cattle results in increased beef production). A more detailed study could be warranted to explore lag effects and compound efficiencies across dairy and beef sectors combined.

Due to the large inter-annual variability, we reference the change in emissions intensity not to the specific value in the year 1990, but rather to the inferred value for 1990 based on the longer term historical (linear) trend during 1990-2012.

The large inter-annual variability implies that it would take a considerable number of years to determine whether and by how much trends in estimated emissions intensity are actually changing (as a baseline trend, or as a result of any mitigation measures that may only gradually and marginally accelerate the decline in emissions intensities). A more detailed model-based understanding of how economic and climatic variability affects emissions intensities in New Zealand in any given year (and flow-on effects to subsequent years) would assist in improving long-term forecasts and in demonstrating the effect of additional measures to improve emissions intensity relative to the inter-annual variability.

For the purpose of setting future emissions intensity targets and verifying whether they had been achieved, the large interannual variability strongly suggests that it would be preferable to use averages over several years (at least 3, but preferably 5 years) rather than single year values. An alternative would be to use inferred values based on long-term trends rather than actual values for individual years, both for reference and target years. The advantage in using inferred long-term trend derived values would be that an inferred value for the year 2030 could be reasonably reliably obtained from the emissions intensity trend from 2020-

2030, whereas the use of averages would have to wait until 2032 to provide the 5-year average value for 2030 based on emissions 2028-2032. Over a finite period of 10 years, linear fits to data are likely to be sufficient (for the historical period 1990-2012, linear and non-linear fits provide almost identical goodness-of-fit results; differences between linear and non-linear fits become noticeable only over longer time periods).

3.4 Impacts of climate change on emission and intensity trends

Climate change itself has the potential to affect the emissions intensity of livestock production in New Zealand, given the dependence on non-irrigated grass growth especially for non-dairy sectors (see e.g. Figure 9). However, the existing literature provides insufficient information on the long-run impacts of climate change on emissions intensities. Given the opposing signals from climate change on pasture production in different parts of the country and multiple interacting trends of increasing irrigation, pasture improvements and changes in management practice including increasing reliance on off-farm feed and integration between dairy and beef production, we consider it impossible at this stage to estimate the potential impact of climate change on emissions intensities in New Zealand. This may be worth a separate detailed study.

A secondary affect may be that historical rates of interannual intensity variation may increase, as climate variability increases. This is worth noting but we were unable to quantify this within the scope of this report.

3.5 Impacts of alternative metrics to calculate CO_2-equivalent emissions

Total emissions in this report are expressed in CO_2-equivalents, based on using 100-year Global Warming Potentials (GWP_{100}) as reported in the 4th Assessment Report by the Intergovernmental Panel on Climate Change and adopted for reporting emissions under the UNFCCC in the post-2012 period. Other metrics such as the Global Temperature Change Potential (GTP) would markedly change the relative contributions from CH_4 and N_2O to CO_2-eq emissions (see also the IPCC Synthesis Report 2014). While the adoption of different metrics would not have a major influence on the trend of absolute emissions, it would affect the reported trend in emissions intensities, if, for example, increasing intensification tends to result in lower emissions intensities of CH_4 but a much lesser reduction or even increase in the emissions intensity of N_2O.

This is indeed reflected in historical trends for New Zealand: the rate of decline in emissions intensities for dairy in particular for the period 1990-2012 would be much lower if GTP_{100} (i.e. the Global Temperature Change Potential with a fixed time horizon of 100 years) were used to report CO_2-equivalent emissions, but higher if GWP_{20} were used. Adopting the GWP_{100} values as reported in the IPCC 5th Assessment Report (which raises the value of CH_4 relative to CO_2 to 28 rather than 25 and slightly lowers the value for N_2O) would not affect emissions intensity trends significantly.

The results for historical emissions intensity trends under different metrics are summarised in Table 7. Alternative metric choices would also somewhat affect the expected future rate of decline in emissions intensities, due to the shifting balance between gains in CH_4 emissions intensity and N_2O emissions intensity as discussed in the preceding section.

Table 7. Emissions intensity trends for the period 1990-2012, based on different metrics to aggregate CH_4 and N_2O emissions into CO_2-eq emissions.

SECTOR	GWP_{100} (AR2)		GWP_{100} (AR4)		GWP_{100} (AR5)		GTP_{100} (AR5)		GWP_{20} (AR5)	
CH_4/N_2O values	*21*	*310*	*25*	*298*	*28*	*265*	*4.3*	*234*	*84*	*264*
Dairy	-0.8%		-0.8%		-0.8%		-0.5%		-1.0%	
Beef	-1.1%		-1.1%		-1.1%		-0.8%		-1.2%	
Sheep	-1.3%		-1.3%		-1.3%		-1.2%		-1.3%	

CH_4 and N_2O values indicate the conversion factor from one kg of gas to one kg of CO_2-eq emission based on alternative metrics, including regular updates by the IPCC. AR2 values (issued in 1995) were used in UNFCCC reporting up to 2012, AR4 values (issued in 2007) are used from 2013 to at least 2020. AR5 values represent the latest update and were issued in 2013.

We note that for future projections, there is little scientific or economic justification at the global level for using a fixed GTP_{100}, as virtually all studies published on this matter agree that this would increase global abatement costs. By contrast, there would be good scientific justification for using a time-dependent or dynamic metric (such as a time-dependent GTP or its economically-based close relative, the so-called Global Cost-Effectiveness Potential, GCP). In these metrics, the weighting for CH_4 increases consistently over time from currently low values (similar to GTP_{100}) to values much higher than for GWP_{100} in 2050 and beyond (with a weighting greater than 50, and potentially as high as 100). Such a dynamic change would in theory deliver the most cost-effective abatement if the policy goal is to minimise peak warming (which would derive naturally from the internationally agreed goal of limiting temperature increases to 2°C relative to pre-industrial levels). Figure 12 illustrates the range of potential outcomes and implications of alternative greenhouse gas metrics for emissions from New Zealand's agricultural sector, for the maximum efficiency baseline only. In particular it demonstrates the extreme apparent increase in agriculture emissions over time under the globally cost-minimising GCP metric. Use of a time-dependent metric, even though this would appear most consistent with the global objective of ensuring cost-minimisation to reach an agreed global mitigation goal, clearly would have major implications for long-term emissions trends and the ability for New Zealand to meet future emissions targets, but the implications of alternative metrics are not evaluated further in this report as they reflect a policy choice.

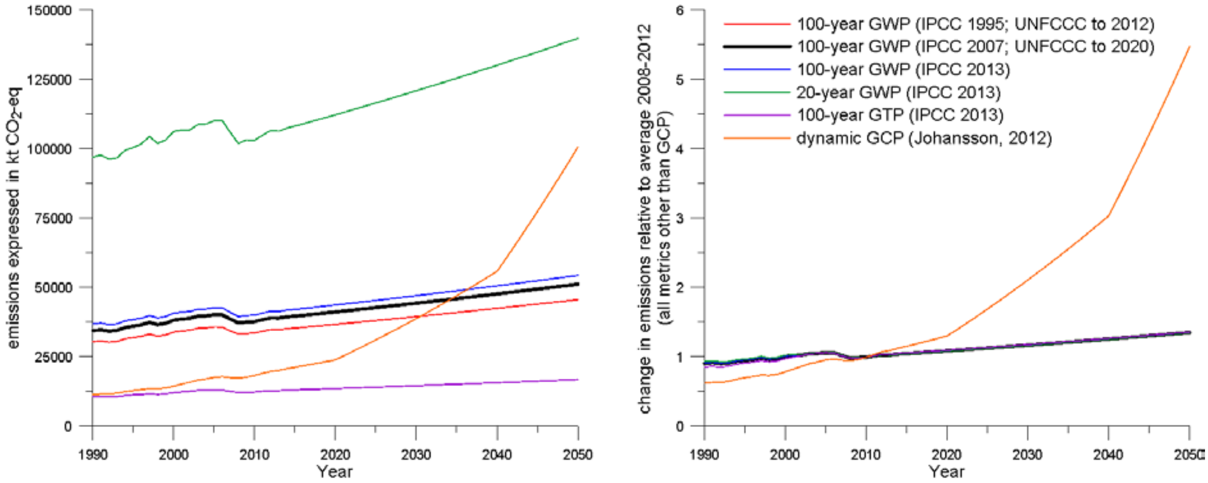

Figure 12. Illustrative comparison of the maximum efficiency baseline emissions for six different greenhouse gas metrics. Left panel shows absolute emissions (expressed in CO_2-eq as defined by the metric, relevant for comparison with emissions from CO_2-intensive sectors, as CO_2 is used as the reference gas for all these metrics and its weight remains unchanged), right panel shows emissions relative to average in 2008-2012. The metrics used are: 100-year GWPs used in UNFCCC reporting up to 2012, 100-year GWPs used in UNFCCC reporting to 2020 and used in this report, 20-year and 100-year GWPs as presented in the latest IPCC assessment report in 2013, 100-year GTPs as presented in the latest IPCC assessment report in 2013, and a dynamic GCP (cost-effectiveness potential, with metric values designed to minimise the global abatement cost for a goal of limiting warming to 2°C).

4. Mitigation options and scenarios

We evaluated the changes in absolute emissions and emissions intensities for the dairy, beef and sheep sectors, as well as agriculture emissions overall, for a range of different intervention options. We provide indicative costs or cost-benchmarks where possible, but emphasise that a full economic analysis of the mitigation options, especially of packages of mitigation options, was not possible within the scope and time frame of this report. Similarly, we indicate policy options/requirements to support the adoption of the various mitigation options, but the transition and transaction costs and details of policy design and implementation were outside the expertise of the authors and scope of this report.

Mitigation options can be grouped broadly into measures that are targeted at reducing absolute emissions (relative to projected baselines) and measures that are targeted at reducing emissions intensity.

All measures considered in this report that reduce absolute emissions would also reduce emissions intensity[2], but the reverse is not true: some measures reduce emissions intensity but increase emissions per animal (notably, accelerated performance increases). This means that absolute emissions in New Zealand would increase under such measures, unless they were coupled with direct controls on the total number of animals or a cap on the quantity of product produced. The implications of intensity-based measures for global emissions depend on whether a production increase in New Zealand displaces livestock production that would have occurred elsewhere, and the emissions intensity of this displaced production compared to that in New Zealand. Such global-scale consequences are highly

[2] Note that this is not necessarily the case for all mitigation approaches; some possible measures, such as de-intensification, could result in *reduced* absolute emissions but *increased* emissions intensity if they also result in reduced production per animal. Such measures have not been considered in this report.

uncertain and have not been explored in this report, but could warrant separate analysis to support potential policy choices. At a national level, measures such as accelerating animal performance can currently only be considered a mitigation option if emissions intensity, rather than absolute emissions, is considered to be an appropriate metric to assess climate change outcomes.

For each sector, and for agriculture as a whole, we estimate in Section 5 the effectiveness of a total package of mitigation options, considering those elements presented in Section 4 that are additive within an overall farm system. The effectiveness of mitigation options is evaluated against different baselines, and the overall mitigation outcome compared with the range of baseline scenarios.

We have not considered scenarios where individual animal performance and stocking rate are adjusted independently to minimise emissions for a given quantity of product produced. This could be done by working backwards from a known amount of product to determine the combinations of individual animal performance and stocking rate that minimise emissions intensity. This type of analysis requires a tool where individual values can be easily manipulated independently; the greenhouse gas emissions inventory and reporting tool used in this report has not been constructed to facilitate this type of analysis although it would be valuable if minimising emissions, rather than maximising economic output, were considered a policy priority.

Mitigation options for dairy fall into the following four categories:

Absolute emissions reductions, based on:

1) increased use of supplementary feeds which reduce the nitrogen content of the animal diet, and hence nitrogen excretion, and reductions in the total nitrogen fertiliser applied per animal
2) new technologies (vaccine, inhibitor, selective breeding for low-CH_4 emitting animals), including re-introduction of DCD to reduce leaching and nitrous oxide emissions
3) changes in farm management, using increased temporary housing and expanded opportunities for manure management.

Reductions in emissions intensity, based on:

4) accelerated improvement in animal performance.

For both beef and sheep, mitigation options fall into the following two categories:

Absolute emissions reductions, based on:

1) new technologies (vaccine, selective breeding for low-CH_4 emitting animals)

Reductions in emissions intensity, based on:

2) accelerated improvement in animal performance

Options for sheep and beef are more limited given the relatively low input management of these animals, and hence the unavailability or economic/practical infeasibility of the large-scale implementation of measures such as supplementary low N feeding or temporary housing. Fertiliser use for those sectors is rather low (in the order of 10% each of total fertiliser use), and hence while limitations in fertiliser inputs were modelled, the resulting changes are so small that they are not reported separately.

As stated earlier, we did not consider mitigation measures associated with constraints on production or available land, a carbon tax or inclusion of agriculture in the NZ-ETS, or regional/catchment-based nitrogen limits or constraints on irrigation. However, given issues around nutrient leaching and some irrigation plans, we consider that more detailed, spatially explicit modelling of overall nitrogen loading and irrigation requirements under various growth scenarios would be highly desirable to ensure such potential non-climate constraints on baseline emissions trends can be quantified more robustly than possible in this report. Such information would be crucial for determining the effectiveness and relevance of regional or farm-level mitigation actions.

4.1 Reduction in nitrogen inputs

Given the relatively high protein and hence high nitrogen (N) content of New Zealand pastures, New Zealand's grazing animals consume considerably more N in their diet than they require for their optimal growth and productivity. High pasture N content is needed for high pasture yields per hectare, but not for the growth/productivity of animals themselves. As a result, much of the N consumed by animals is surplus to the animals' requirements and is excreted onto pastures in the form of dung and urine, where it contributes to nitrate leaching and nitrous oxide emissions.

However, dairy production in New Zealand is increasingly making use of supplementary feed to ensure optimal performance for all animals and to balance out variations in pasture growth resulting from climate variability. Many of the supplementary feeds have lower N content and hence their accelerated use (relative to usage rates assumed in baseline scenarios) would result in lower N excretion rates and hence lower nitrous oxide emissions.

A second, related mitigation option is to increase the efficiency in which fertiliser N is used so that the use of N fertiliser per unit area declines. This does not necessarily imply lower pasture production, but would require more careful management of nutrient flows. Mechanisms by which this could be achieved also include more reliance on purchased feed and the growing of forages with high yield per hectare.

We have restricted mitigation options based on those approaches to dairy systems. Specifically, we quantified emissions reductions that would be achieved by two specific scenarios: one where the N content of dairy cattle diet drops over time from the current 3.7% to 3%, and one where fertiliser input drops to 85% of current levels per animal by 2035. These scenarios are considered feasible, without reducing production relative to baseline, given that fertiliser use per animal has dropped by 18% since 2005 despite record dairy pay-outs and record per animal and per hectare performance. A major factor in this is pressure being applied to the dairy sector over water quality which has resulted in the extensive use of nutrient budgeting models and a major effort by the dairy sector to encourage the more efficient use of N fertiliser. The Dairying and Clean Streams Accord 2003 requires all dairy farmers to report on nutrient flows based on a nutrient budgeting tool such as 'OVERSEER' for the purposes of understanding management decisions relating to fertiliser use. The National Policy Statement on Freshwater Management could, subject to regional implementation, intensify this pressure and may result in nitrogen discharge limits in particular regions.

There is a risk of pollution swapping in that we have not considered any emissions incurred in the production of supplementary feeds in the overall agriculture emissions budget. If feeds are imported from outside New Zealand (e.g. Palm Kernel Expeller, PKE), these emissions would not affect the national emission inventory but could pose a reputational risk to New Zealand. For those feeds likely to be produced in New Zealand (maize, forage rape, fodder beet, cereals), we consider the additional emissions likely to be small as N inputs for these crops are similar to the N input rates for the pasture they replace and the area of production is small relative to pasture; we therefore assume that increased domestic production of supplementary feeds would not increase fertiliser use. However, a more detailed modelling of the total lifecycle emissions of a high-supplement regime would be desirable to ensure the robustness of this option, especially under the maximum efficiency scenario and when this is combined further with accelerated performance per animal as additional mitigation option, which would imply very high total feed consumption rates.

Table 8. Summary of mitigation outcomes from reduction in nitrogen inputs

	Reduce N content in diet (dairy only)	**Limit additional N inputs (dairy only)**	**Combined mitigation options**
Assumed maximum adoption rate	National (100% across the sector)	National (100% across the sector)	National (100% across the sector)
Date when option could be introduced	Now; linear increase until maximum adoption rate	Now; linear increase until maximum adoption rate	Now; linear increase until maximum adoption rate
Date for full implementation	2035	2035	2035
Reduction in CO_2-eq sector emissions, relative to baselines in 2030	Max: 2.8% Min: 2.8%	Max: 0.9% Min: 0.7%	Max: 3.7% Min: 3.4%
Reduction in CO_2-eq sector emissions, relative to baselines in 2050	Max: 5.6% Min: 5.5%	Max: 1.7% Min: 1.0%	Max: 7.2% Min: 6.5%
Able to be captured in national inventory	Yes (though not currently accounted)	Yes	Yes (though not currently accounted)
Implications for production and on-farm costs	Greater reliability of production; costs limited but not modelled directly	Requires more careful nutrient budgeting and planning	(combined)
Potential measures that could support implementation	Information, support programmes	Information, N budgeting tools, voluntary accords, pricing	(combined)

4.2 Introduction of additional technologies

Current research in New Zealand and overseas aims to develop additional technologies that would reduce methane emissions from enteric fermentation through a vaccine or inhibitors that target methanogens in the rumen, or through the incorporation of traits that result in naturally lower-emitting animals being included in breeding indices.

The nitrification inhibitor DCD has been demonstrated to reduce nitrous oxide emissions and its use has been incorporated into the national inventory as mitigation option. However, DCD has been withdrawn from market following discovery of residues in milk. If a safe level of DCD residues in milk can be established and accepted through an international food safety standard, and its re-introduction is considered compatible with New Zealand's market demands, it could also contribute to nitrous oxide mitigation in New Zealand.

Common to all these approaches is that they are not currently available; the timing of their potential introduction remains therefore speculative, and their availability as mitigation option cannot be guaranteed. For vaccines and inhibitors, the amount of emissions reductions that can be achieved is also highly uncertain until they have reached the full proof-of-concept stage using substances that are consistent with market requirements and animal welfare.

We assume that a vaccine could be applied to dairy, beef and sheep, but an inhibitor would be applied only to dairy given its likely requirement for a higher frequency of administration (dairy farmers already use daily drenching systems, or alternatives such as applying substances to pasture, water troughs, or supplementary feed).[3] Since a vaccine and inhibitor target similar microbes in the rumen, their combined application may not have an additive mitigation effect. In this report, we assume that a vaccine would reduce emissions by 20% (the minimum considered feasible for practical use), while an inhibitor would reduce emissions by 30% if used in isolation (based on a 60% reduction from existing inhibitors in animals on Total Mixed Ration diets), but only by another 10% if used on top of a vaccine in dairy systems (i.e. a total of 30% reduction for a combination of vaccine and inhibitor for New Zealand dairy systems). We stress the high degree of uncertainty around our choice of values for vaccines and inhibitors and they should not be interpreted as predictions; rather they are illustrative of what impact these types of technologies could have.

The other technologies in this category are assumed to be fully additive, i.e. for dairy, a technology package consists of vaccine plus inhibitor, selective breeding, and DCD use. For sheep and beef, DCD would be prohibitively costly at current prices, and hence a vaccine combined with selective breeding is the only package considered feasible.

Another difficult issue when considering these technologies is the rate of adoption that can be achieved. This will depend on the direct cost of the technologies, the presence of any government or industry policy to incentivise or mandate their use, any co-benefits for productivity, and any market premiums for low-emissions food production (but equally any market barriers to their use). Based on current knowledge, none of the mitigation options considered in this report is expected to result in significant production penalties or overall

[3] An inhibitor could potentially be provided in extensive sheep and beef systems via a lick block; however, individual animal intake via block is highly variable. Such an inhibitor would also need to be stable, effective when dose is intermittent, non-toxic when individuals overdose etc. Since all of those effects are highly speculative at this stage, we assume only an effective vaccine for sheep and beef.

constraints on production, although some may imply upfront investment costs or on-going implementation costs. It is plausible that increased production could be a co-benefit from effective methane mitigation through a vaccine or inhibitor, but evidence for this is ambiguous ay present. Given the higher frequency of animal interactions in dairy systems, dairy industry’s centralised structure, and strong relationships between processors and farmers, the potential rate of uptake would generally appear to be greater in these systems.

Under a high uptake scenario, we assume that a vaccine/inhibitor combination would be adopted by 2030 by 90% of dairy farmersand 50% of sheep and beef farmers would adopt the vaccine. Under a low uptake scenario, we assume that a vaccine/inhibitor combination would be adopted by 60% of dairy farmers and 20% of sheep and beef farmers would adopt the vaccine, and these adoption rates would be achieved only by 2050 rather than 2030. For selective breeding, we evaluated two different levels of adoption (30 and 80%). We stress that the adoption levels assumed here are based on simple exploratory assumptions only and are not intended to be forecasts; actual uptake will depend strongly on the mitigation effectiveness and cost, type and strength of domestic policy measures to support their adoption and overseas market responses.

Given that except for DCD, none of the measures considered in this category is currently available in market-ready form, we are unable to provide cost estimates. Economic analysis is therefore constrained to providing provide benchmarks for the maximum cost for a vaccine or inhibitor that would make their use cost-effective at a given carbon price.

Table 9. Summary of mitigation outcomes from introduction of additional technologies

	Vaccine (+ inhibitor)	**Selective breeding**	**DCD (dairy only)**
Assumed effectiveness	20% [30%] reduction below baseline CH_4 emissions in sheep/ beef [dairy]	10% reduction below baseline CH_4 emissions	~60% reduction below baseline N_2O emissions from excreta
Assumed maximum adoption rate	High adoption: 50% [90%] in sheep/beef [dairy] Low adoption: 20% [60%] in sheep/beef [dairy]	High adoption: 80% Low adoption: 30%	40% of dairy pastures
Date when option could be introduced	2020; linear increase until maximum adoption rate	2020; linear increase until maximum adoption rate	2020; linear increase until maximum adoption rate. Note that a current key barrier to (re-) introduction is regulatory approval and international market acceptance.
Date for full implementation	High adoption: 2030 Low adoption: 2050	2050	2030

Inferred adoption rate by 2030	High adoption: 50% [90%] in sheep/beef [dairy] Low adoption: 10% [30%] in sheep/beef [dairy]	High scenario: 40% Low scenario: 15%	
Reduction in CO_2-eq sector emissions relative to maximum and minimum efficiency baselines in 2030, for low and high adoption rates	High adoption: Max: 18.8% (dairy) 7.7% (shp/bf) Min: 18.7% (dairy) 7.7% (shp/bf) Low adoption: Max: 4.2% (dairy) 1.0% (shp/bf) Min: 4.1% (dairy) 1.0% (shp/bf)	High adoption: Max: 1.9% (dairy) 2.1% (shp/bf) Min: 1.8% (dairy) 2.1% (shp/bf) Low adoption: Max: 0.7% (dairy) 0.8% (shp/bf) Min: 0.7% (dairy) 0.8% (shp/bf)	Max efficiency: 1.2% Min efficiency: 1.4%
Reduction in CO_2-eq sector emissions relative to maximum and minimum efficiency baselines in 2050, for low and high adoption rates	High adoption: Max: 19% (dairy) 7.6% (shp/bf) Min: 18.8% (dairy) 7.7% (shp/bf) Low adoption: Max: 12.7% (dairy) 3.1% (shp/bf) Min: 12.5% (dairy) 3.1% (shp/bf)	High adoption: Max: 5.6% (dairy) 6.1% (shp/bf) Min: 5.6% (dairy) 6.2% (shp/bf) Low adoption: Max: 2.1% (dairy) 2.3% (shp/bf) Min: 2.1% (dairy) 2.3% (shp/bf)	Max efficiency: 1.2% Min efficiency: 1.4%
Able to be captured in national inventory	Yes in principle, but not implemented	Yes in principle, but not implemented	Yes, implemented
Implications for production and on-farm costs	No direct production penalty (some hope for production increase, but this cannot be confirmed at this stage). At carbon price of \$25/t CO_2-eq, a reduction of 30% of CH_4 emissions for dairy cattle equates to \$15/animal/year, and a reduction of	No direct production penalty. However, there is an opportunity cost from constraining on-going breeding programmes if a low-emissions trait is added – hence widespread adoption unlikely without additional incentives. We cannot put a cost on	Varies significantly due to pasture growth response. At a cost of \$250/ha for DCD, the cost per avoided GHG emissions from an average dairy farm is \$650/tCO_2-eq. This means DCD use is very unlikely to be driven by GHG emissions pricing.

	20% for sheep to $1.50/animal/year	this as the information needed to do this is not expected to be available until autumn 2015	However, DCD substantially reduces nitrate leaching, which could be a major factor influencing its uptake along with farm-specific production goals.
Potential measures that could support implementation	Information, voluntary agreements, price incentive, regulation	Information, voluntary agreements, price incentive, regulation	Information, voluntary agreements, price incentive, regulation

4.3 Partial animal housing and enhanced waste management systems

The increasing intensity of dairy systems management opens the possibility that animals could be housed for increasing periods of time and/or spend part of their time on stand-off and feed pads. Confinement of animals means that animal excreta (dung and urine) can be captured and treated before being spread back onto land. At present, manure management accounts for only a small part of overall emissions from agriculture (approximately 2.4% in 2012 based on the current inventory and methodology); hence significant mitigation of total emissions could arise only after a significant system change towards temporary animal housing and enhanced manure management. This is considered unfeasible for sheep and beef operations, given their extensive operation, but feasible for dairy farming.

We stress that at present, based on the current inventory, a shift towards animal housing and associated manure management would result in an *increase* rather than *decrease* of emissions. This is for two reasons: (1) manure management generates much higher methane emissions from anaerobic decay of organic matter in manure ponds than when the same amount of excreta are deposited onto pastures directly where the decay is mostly aerobic, and (2) the current emission factor from dung deposited directly onto pastures is significantly lower than from directly deposited urine, but once manure is spread in liquid form back onto pastures, all N contained in manure is assumed to have the same emission factor as directly deposited urine. This means that estimated net N_2O emissions from manure stored and subsequently spread onto pastures are higher than from the same amount of manure deposited separately onto pastures as dung and urine by grazing animals. Work is currently underway to obtain a New Zealand-specific emission factor for manure from anaerobic lagoons spread onto pastures.

In principle, manure management systems of sufficiently large size could allow delaying the spreading of manure by up to six months and thus enable the spreading to be timed such that it occurs only when conditions are less conducive to producing N_2O (for example during the dry summer months). However, the scientific evidence to support a lower emission factor based on such enhanced manure management practice is limited for New Zealand at present.

Nonetheless, for the purpose of exploring a possible future mitigation option around enhanced manure management, we make the following two (ambitious) assumptions:

1. all CH_4 from additional manure stored in anaerobic ponds is captured and flared, hence even a substantial increase in the amount of manure collected and stored on farms will not increase CH_4 emission from manure management, and
2. the emission factor for N_2O from manure spread onto pastures is only half the emission factor compared to the emission factor of animal urine deposited directly onto pastures; this assumes that farmers will choose the timing of manure spreading such that it minimises N_2O emissions (which would likely also reduce N leaching), and scientific evidence will be available to support such a lower emission factor.

We stress that this scenario is both ambitious (for capturing CH_4) and unproven (for N_2O; even if a lower emission factor as such is plausible for manure management systems, the amount by which it might be lower in practice compared to the default for directly deposited animal urine is unproven and speculative only at this stage, and would depend on actual on-farm practice, incentives and regulations).

We note that the capture of CH_4 generated from anaerobic ponds is critical to this approach actually resulting in emissions reductions; based on the current inventory, total net emission would *increase* even if condition 2 above holds (i.e. if manure spread onto pasture indeed has only half the emission factor of animal urine) but condition 1 does not, i.e. if CH_4 from anaerobic ponds were to be released to the atmosphere rather than captured and flared. On the positive side, if CH_4 were not only captured but also used to generate electricity or replace on-farm electricity use, it could result in even greater emissions savings as it would also displace fossil fuel consumption. However, the size of this additional emissions reduction has not been evaluated here since it would depend critically on energy sector policies, including electricity prices and feed-in tariffs and policies and the carbon content of wholesale electricity in New Zealand by 2030 or 2050. The economics of biogas generation and use are also challenging with a requirement for a large initial capital investment.

Table 10. Summary of potential mitigation outcomes from expanded and enhanced manure management

	Enhanced waste management with full CH_4 capture (dairy only)
Assumed maximum adoption rate	Dairy animals are housed 30% of the time (national average); all methane generated from anaerobic ponds is captured and flared
Date when option could be introduced	Now; linear increase until maximum adoption rate
Date for full implementation	2050
Reduction in CO_2-eq sector emissions, relative to baselines in 2030	Max: 1.2% Min: 1.2%
Reduction in CO_2-eq sector emissions, relative to baselines in 2050	Max: 2.1% Min: 2.1%
Able to be captured in national inventory	Yes (although requires modification to currently hard-wired assumptions)

Implications for production and on-farm costs	Implies significant shift in farm systems where this is implemented; capital investment for housing and advanced manure management that ensures full capture and flare of anaerobic CH_4 generated. Costs could be reduced if biogas is used to generate electricity either for on-farm use or fed back into the national grid
Potential measures that could support implementation	Information, water quality policies, regulations to ensure CH_4 capture, regulations and voluntary agreements to support feed-in of biogas-generated electricity

4.4 Accelerating animal/farm system performance

The on-going decline in emissions intensity even in baseline scenarios suggests that accelerating animal and farm system performance could be accelerated further. This could thus represent a viable measure to reduce emissions intensity more quickly, without requiring any animal management or farm system change per se (or at least no change that is not envisaged to occur in the baseline anyway, albeit at a slower pace).

Given that most measures that increase productivity are associated with increased individual animal performance, and this increased performance is generally associated with a higher level of absolute emissions unless stocking rate is adjusted downwards, accelerating performance is only a mitigation option if *emissions intensity* is considered as the appropriate metric to describe emissions outcomes.

Accelerating performance could come in many different forms; it could imply a faster progression of the sector as a whole along a productivity trend, or it could imply improving the performance of the poorest performers in the system. For the purpose of deriving national emissions estimates, it matters relatively little how this aggregate productivity gain is assumed to be achieved – although it clearly could matter considerably for policies designed to achieve such an outcome, especially at the regional and sub-sectoral scale.

We also stress that even where the overall goal is clear, such as improving the performance of the lowest 25% of performers to the average productivity across the sector, it is not a given that this can in fact be achieved. Variation of performance within the sector reflects genuine differences in soil quality, climate conditions, labour costs and supply, distance to processors etc., and these differences cannot necessarily be eliminated. Nonetheless, given the long-term trend towards higher performance makes it a plausible conjecture that the rate of change could be accelerated at least marginally in the national average.

For the purpose of this report, we have assumed that the average level of performance in a sector that is assumed to be achieved by 2050 in the baseline would instead be achieved by 2035, with the same rate of further improvement after 2035 as in the baseline scenario. The continuing acceleration of performance post 2035 implies some very high levels of individual animal performance by 2050. For example, individual milk yield per cow would be approximately 70% higher than current values. Although biologically feasible, achieving these levels of performance in practice may be difficult without considerable changes to current farming practice. As it would be difficult to generate the amount of feed consumed by such very high performing dairy animals from within New Zealand, there is also an enhanced risk of pollution swapping if large amounts of supplementary feed are imported from overseas. However, for national reporting purposes, emissions related to imported feed production are not counted in the national inventory and so do not affect the calculated emissions intensity of production within New Zealand.

Note that for internal consistency, we have only considered scenarios where performance accelerates relative to the performance assumed in the underlying baseline. However, if the long-term baseline trend were one of relatively low efficiency (such as in the minimum efficiency baseline), a key policy goal would be to shift the overall sector performance into the performance assumed in the maximum efficiency baseline scenario, rather than merely accelerating the minimum efficiency trend. The gains possible from such a shift from minimum to maximum efficiency baseline would be considerable, as the difference in emissions intensities between the maximum and minimum baselines are 8-10% in the sheep, beef and dairy sectors. These improvements are considerably greater than the gains that can be made *within* a low-efficiency baseline by simply accelerating the (slow, lower-efficiency) trend.

Table 11. Summary of mitigation outcomes for emissions intensity from accelerated animal performance

	Accelerated performance
Assumed effectiveness	2050 animal performance characteristics achieved by 2035, followed by baseline rates of further improvement 2035-2050
Assumed maximum adoption rate	100% (i.e. improvement of average performance across sector)
Date when option could be introduced	Now
Date for full implementation	2035
Reduction in CO_2-eq sector ***emissions intensity*** relative to baseline in 2030 (in percentage points)	Max: 5.1% (dairy), -0.3% (beef), 2.3% (sheep) Min: 2.2% (dairy), -0.6% (beef), -0.2% (sheep)
Reduction in CO_2-eq sector ***emissions intensity*** relative to baseline in 2050 (in percentage points)	Max: 8.3% (dairy), -0.9% (beef), 6.6% (sheep) Min: 4.4% (dairy), -1.1% (beef), 4.4% (sheep)
Able to be captured in national inventory	Yes if represented by national-level or aggregated statistics; difficult to capture if contingent on farm-scale actions
Implications for production and on-farm costs	Generally strong economic incentive to increase productivity; however, accelerating performance beyond the baseline may

	expose farmers to increased risks, up-front investment costs, and demand for skilled labour
Potential measures that could support implementation	Information, training, support for research, development and demonstration

5. Mitigation packages

5.1 Mitigation of absolute emissions

Most of the options to reduce absolute emissions considered in this report can be combined in packages that are largely additive; the notable exception is the combination of an anti-methanogen vaccine and inhibitors for dairy systems (as discussed above). Figure 13 to Figure 16 show the 'wedges' of mitigation that would be achieved by an appropriate package of mitigation options considered in Sections 4.1 to 4.3, relative to the maximum and minimum efficiency baseline scenarios. Accelerated performance is excluded from those packages, as this would decrease emissions intensity but increase absolute emissions.

We note that the order in which mitigation options are deployed influences their apparent contribution to the overall mitigation result in those graphical illustrations, even though it does not change the actual result. I.e. if options A and B both reduce CH_4 from enteric fermentation by 50%, then showing option A first and then option B in a wedge diagram would indicate that the mitigation from option A is twice that from option B, as option A reduces baseline emissions by 50%, and option B reduces the remaining emissions by another 50%, which is only 25% of the baseline emissions. Conversely, if option B were shown before option A, then option B would reduce 50% of baseline emissions and option A reduce the remaining emission by another 50%, which is only 25% of baseline emissions. The order in which such additive mitigation options are applied clearly has no influence on the end result, but it skews their apparent importance when presented graphically. The choice of sequence made in this report does not reflect an assumption about which options would indeed be chosen first by farmers, they simply reflect one of many possible choices.

For each livestock sector, and for agriculture as a whole, we show the effect of both high and low adoption rates for the new technologies (vaccine, inhibitor, and low-emissions selective breeding); it can be seen that assumptions about adoption rates (and, by implication, policies to incentivise their adoption) have a significant influence on the relative contribution that can be expected from those new technologies.

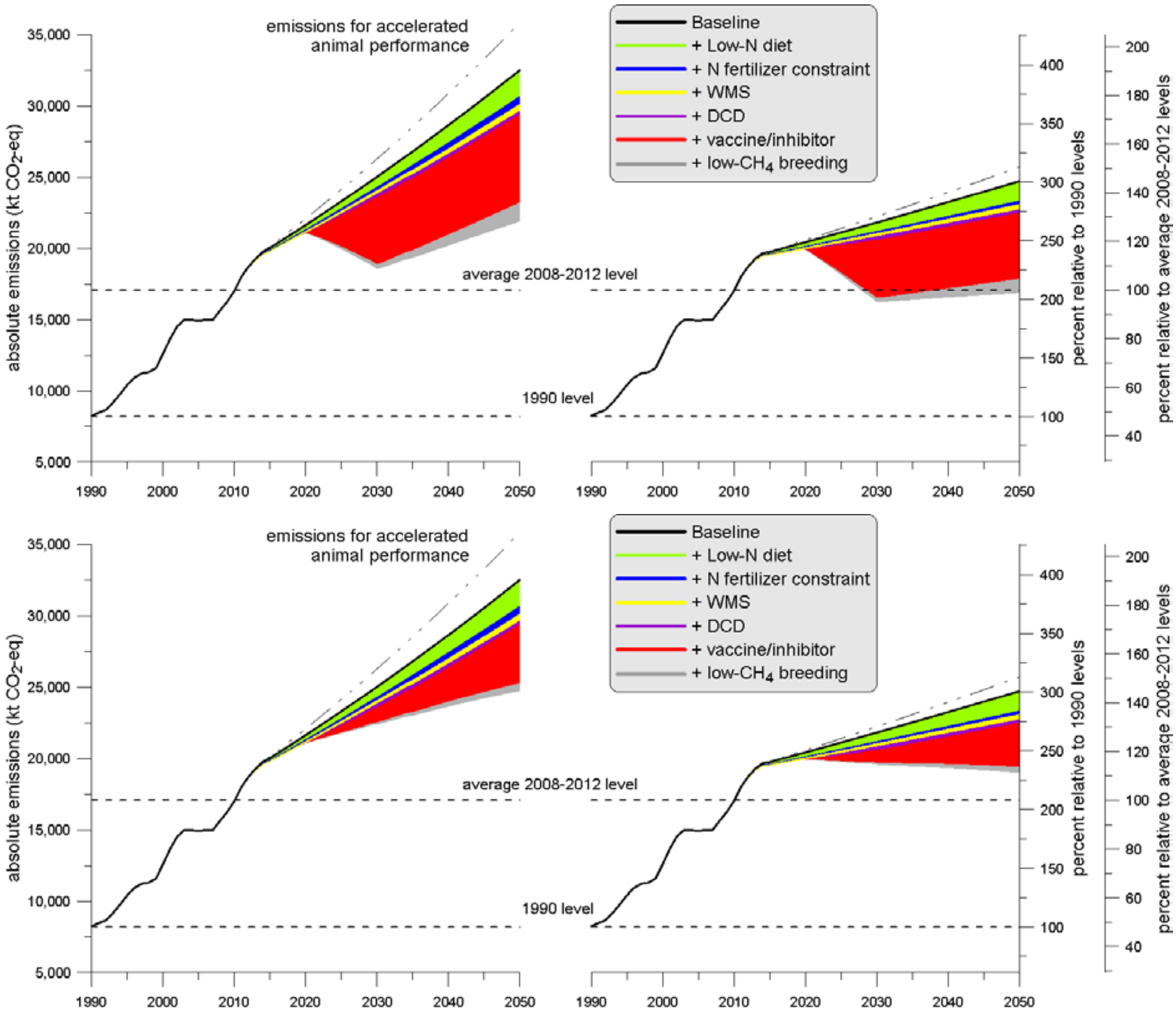

Figure 13. Packages of absolute mitigation options for dairy, against the maximum (left) and minimum (right) efficiency baselines. Top panels show results for high adoption rates, bottom panels for low adoption rates for mitigation based on new technologies (breeding and methane vaccine/inhibitors). For comparison, the figure also shows absolute emissions if enhanced animal performance were implemented (which does not reduce but rather increases absolute emissions).

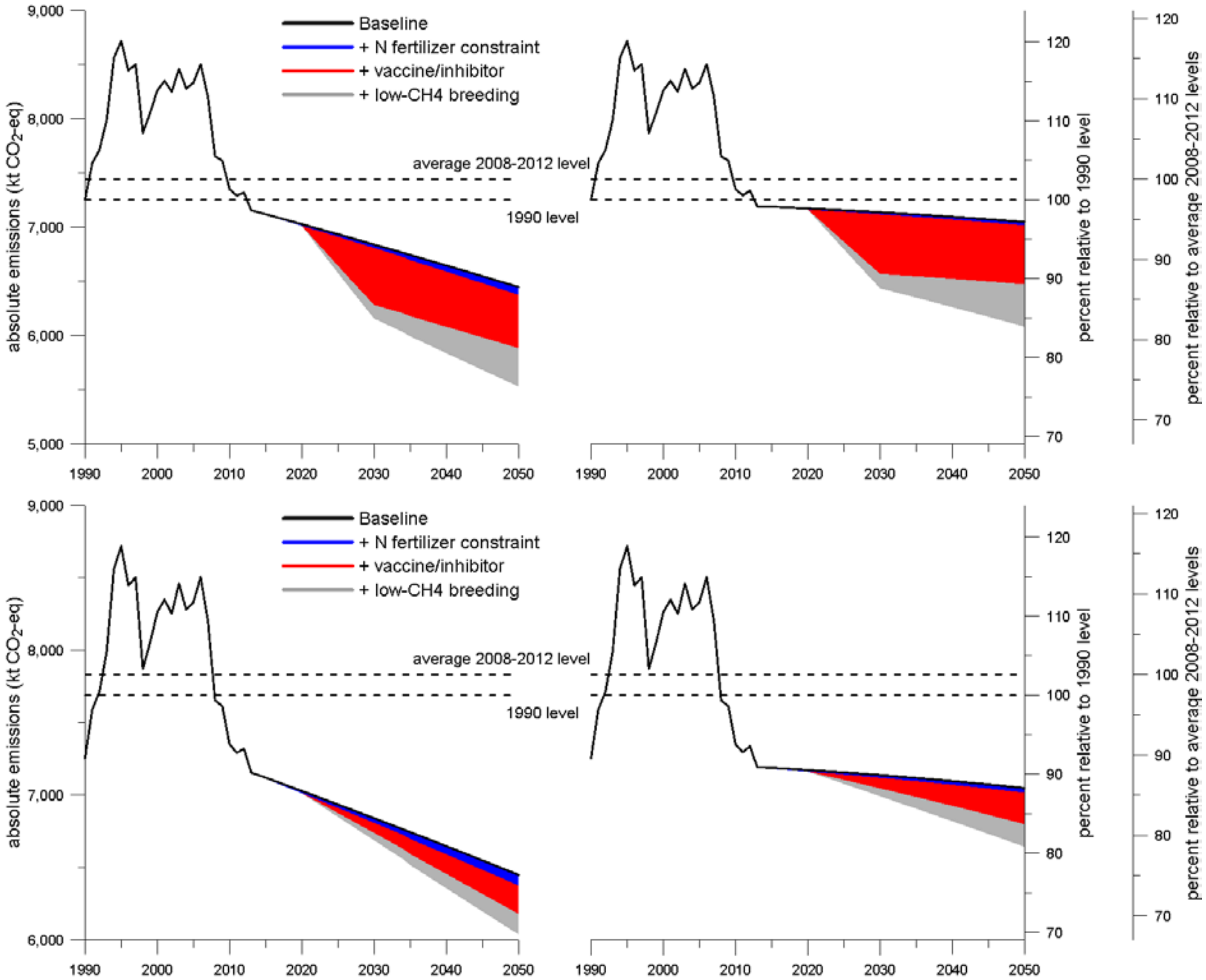

Figure 14. Packages of absolute mitigation options for beef, against the maximum (left) and minimum (right) efficiency baselines. Top panels show results for high adoption rates, bottom panels for low adoption rates for mitigation based on new technologies (breeding and methane vaccine/inhibitors).

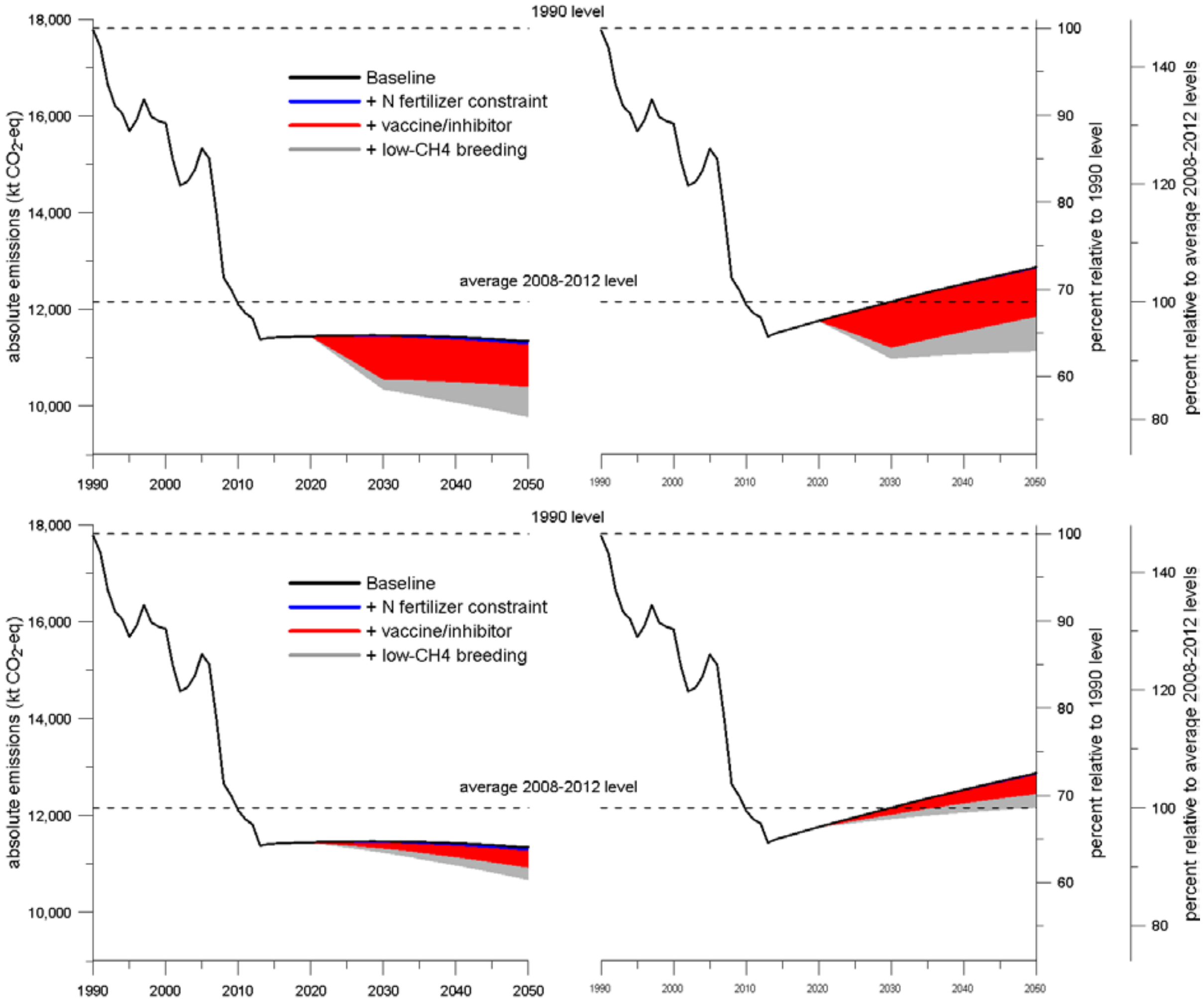

Figure 15. Packages of absolute mitigation options for sheep, against the maximum (left) and minimum (right) efficiency baselines. Top panels show results for high adoption rates, bottom panels for low adoption rates for mitigation based on new technologies (breeding and methane vaccine/inhibitors).

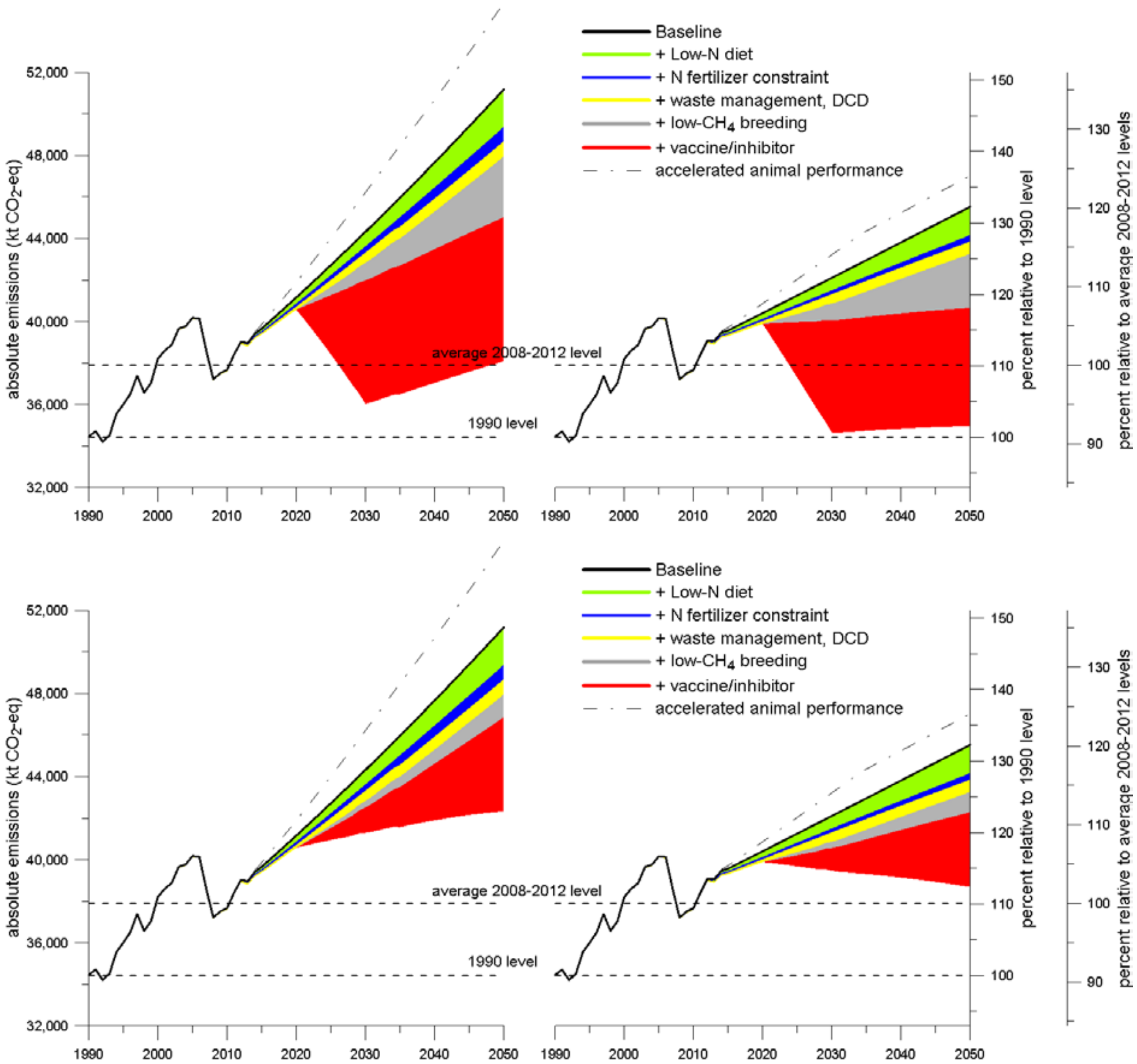

Figure 16. Packages of absolute mitigation options for all agriculture, against the maximum (left) and minimum (right) efficiency baselines. Top panels show results for high adoption rates, bottom panels for low adoption rates for mitigation based on new technologies (breeding and methane vaccine/inhibitors). For comparison, the figure also shows absolute emissions if enhanced animal performance were implemented (which does not reduce but rather increases absolute emissions).

We emphasise that the absolute emissions reported in this table are not forecasts of actual baseline emissions nor do they encapsulate all feasible mitigation outcomes. Baseline emissions will depend crucially on international market conditions; mitigation outcomes will, in addition to the options considered in this report, be influenced strongly by non-climate policies relating to water quality, and climate policies that could alter overall production or land-use by livestock sectors beyond the baseline scenarios considered in this report. Such changes could arise from price incentives (including the interaction with land-use by forestry), regulations or voluntary agreements and information measures. These factors could significantly affect production and hence overall agricultural emissions in New Zealand but have not been modelled in this report.

5.2 Mitigation of emissions intensity

As noted above, all mitigations considered in this report that lower absolute emissions also reduce emission intensity relative to their respective baselines. An additional mitigation option to reduce emission intensity is the acceleration of animal performance, which could act in addition to the mitigation achieved by other measures. We emphasise that accelerating animal performance, in the absence of any additional policies to limit land-use or over production, would *increase* absolute emissions within New Zealand. The desirability of pursuing accelerated animal performance as mitigation thus strongly depends on the metric by which mitigation is reported and targets are set for New Zealand.

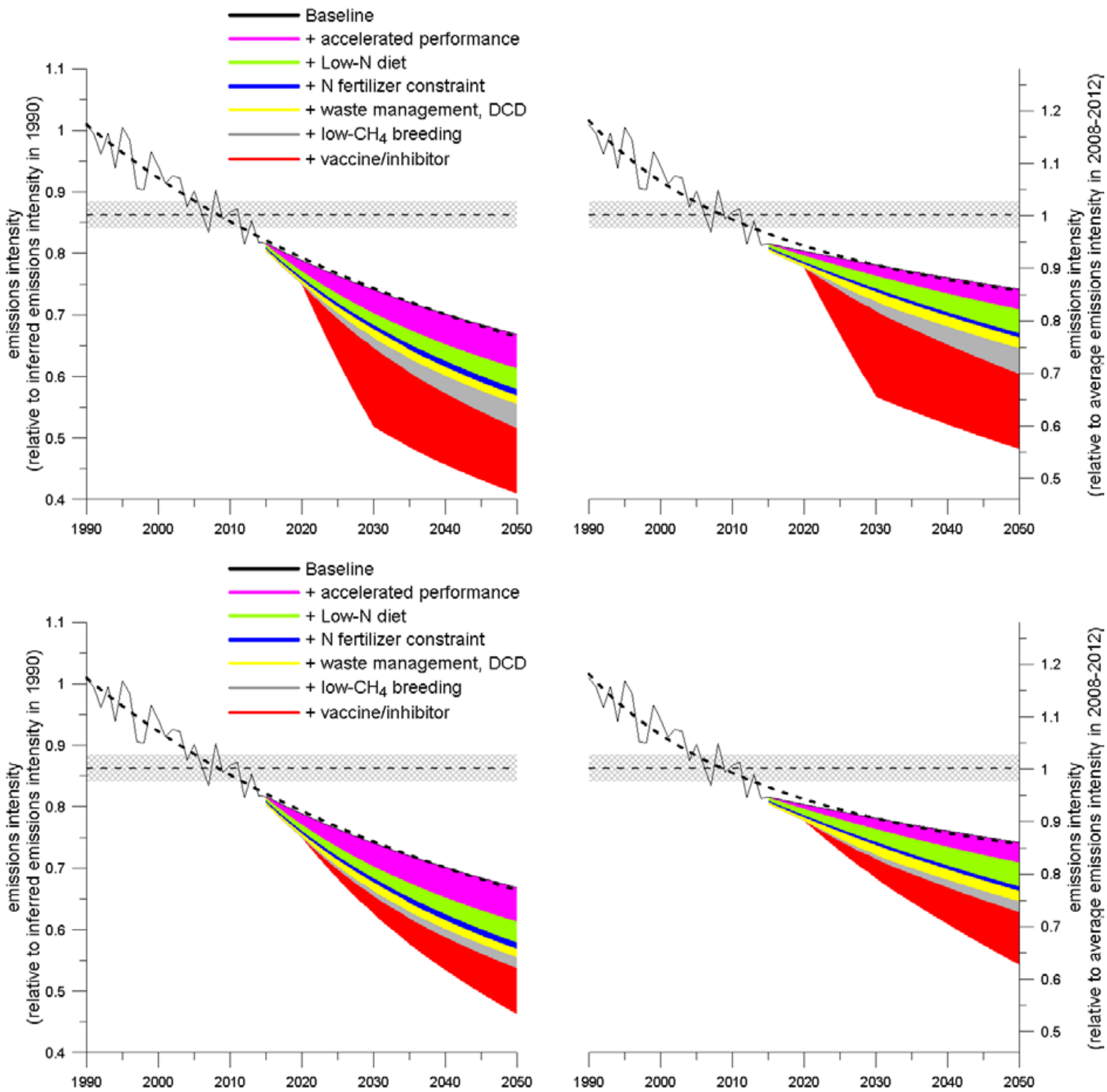

Figure 17. Packages of emissions intensity mitigation options for dairy, against the maximum (left) and minimum (right) efficiency baselines. Top panels show results for high adoption rates, bottom panels for low adoption rates for mitigation based on new technologies (breeding and methane vaccine/inhibitors). The dotted line and shaded area indicates the average emissions intensity for the period 2008-2012 inferred from the long-term historical trend (1990-2012), plus and minus one standard deviation.

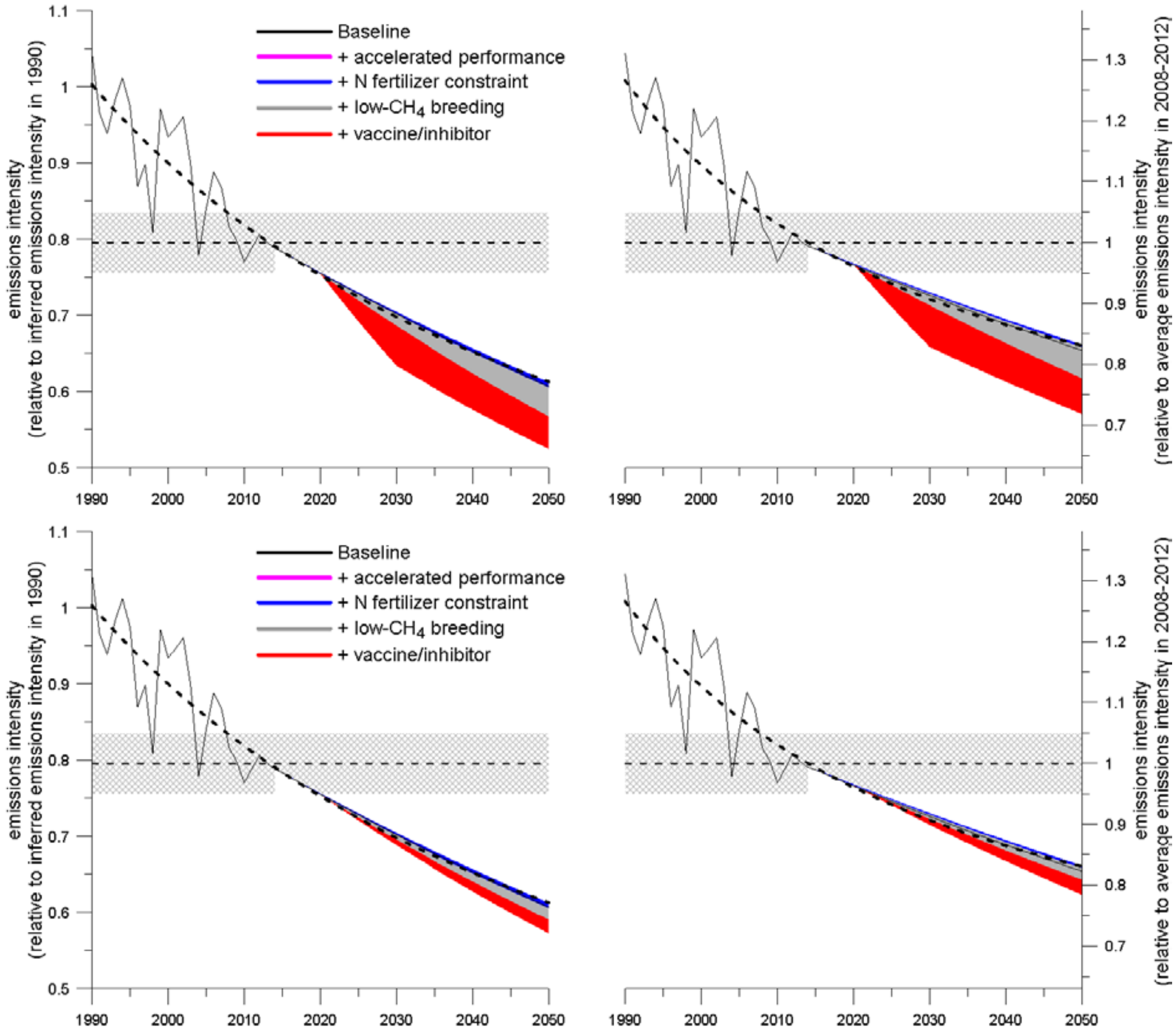

Figure 18. Packages of emissions intensity mitigation options for beef, against the maximum (left) and minimum (right) efficiency baselines. Top panels show results for high adoption rates, bottom panels for low adoption rates for mitigation based on new technologies (breeding and methane vaccine/inhibitors). The dotted line and shaded area indicates the average emissions intensity for the period 2008-2012 inferred from the long-term historical trend (1990-2012), plus and minus one standard deviation.

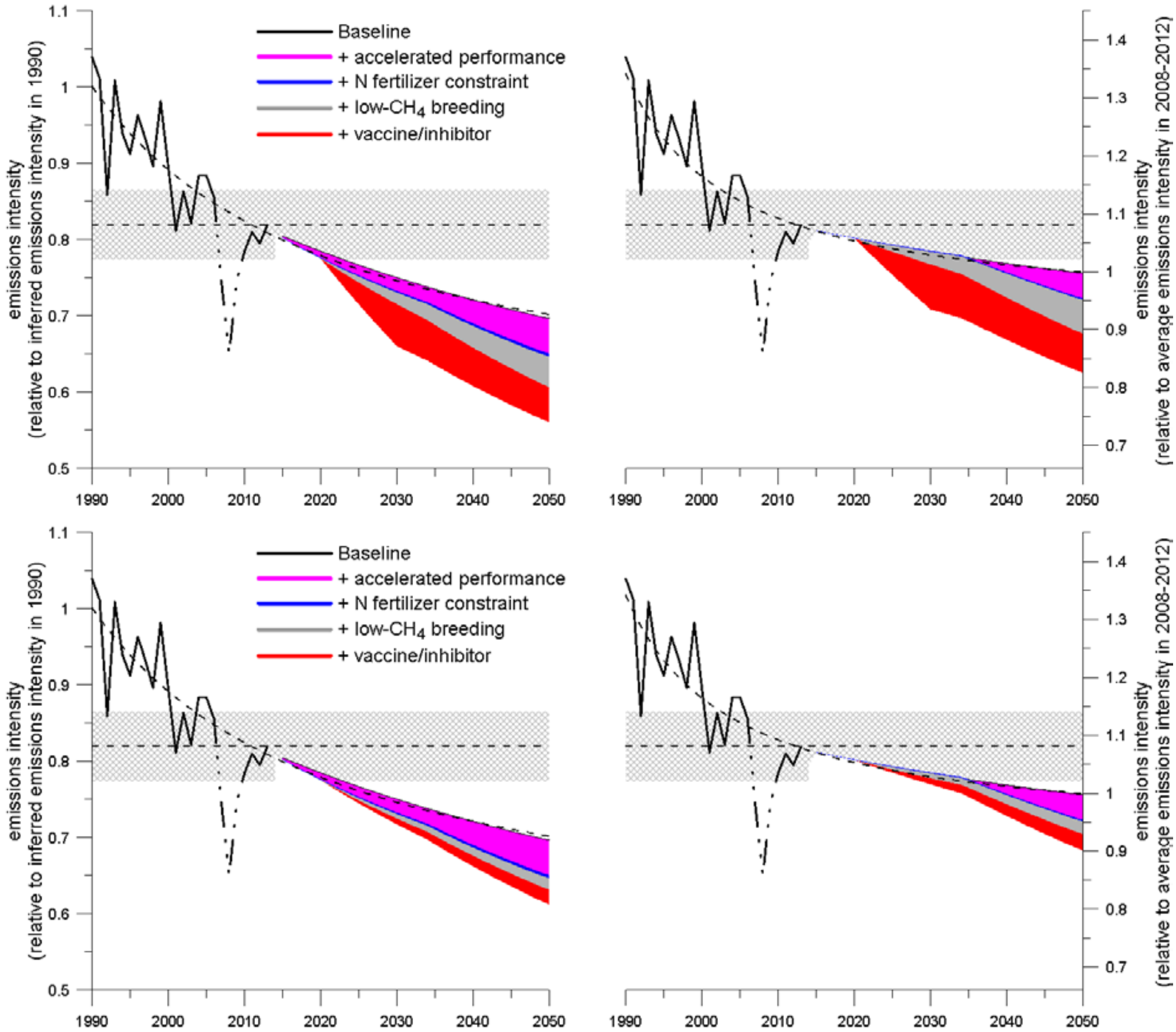

Figure 19. Packages of emissions intensity mitigation options for sheep, against the maximum (left) and minimum (right) efficiency baselines. Top panels show results for high adoption rates, bottom panels for low adoption rates for mitigation based on new technologies (breeding and methane vaccine/inhibitors). The dotted line and shaded area indicates the average emissions intensity for the period 2008-2012 inferred from the long-term historical trend (1990-2012), plus and minus one standard deviation.

To calculate the emission intensity combined across the dairy, beef and sheep sectors, the emissions intensity from each sector was weighted by the sector's absolute emissions. The figure also shows for comparison a 1% per annum exponential decline in emissions intensities. While this rate of decline has been achieved historically from 1990 to 2012 based purely on improved performance, our scenarios indicate that it will be challenging to maintain, let alone improve on, this rate unless there is high uptake and implementation of the full suite of additional mitigation options combined with high rates of improvement in individual animal performance.

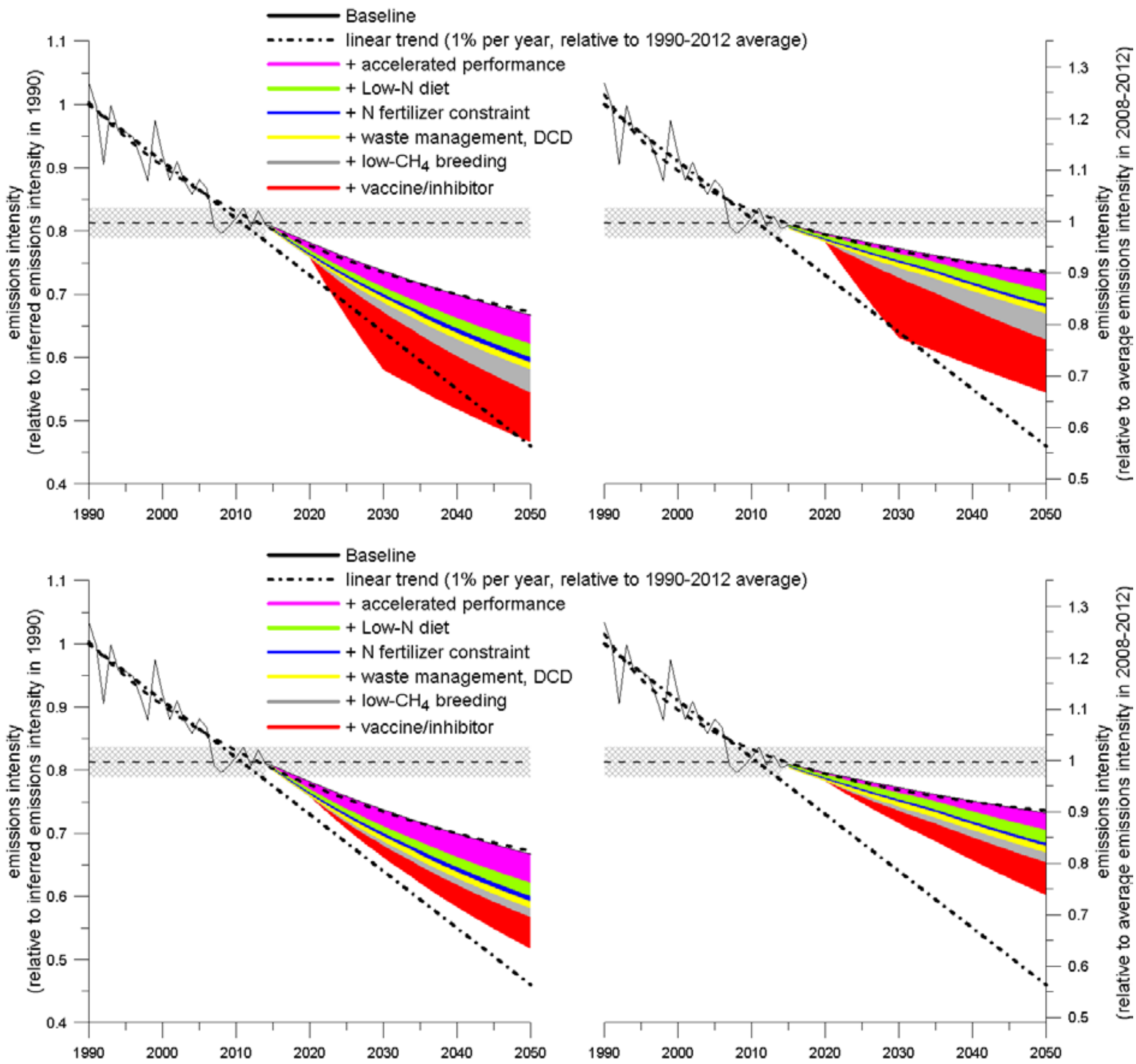

Figure 20. Packages of emissions intensity mitigation options for sheep, against the maximum (left) and minimum (right) efficiency baselines. Top panels show results for high adoption rates, bottom panels for low adoption rates for mitigation based on new technologies (breeding and methane vaccine/inhibitors). The dotted horizontal line and shaded area indicates the average emissions intensity for the period 2008-2012 inferred from the long-term historical trend (1990-2012), plus and minus one standard deviation. The dash-dotted line represents a linear trend of 1% decline per annum (relative to the mean 1990-2012 emissions intensity, including drought-affected years 2007-2009).

5.3 Quantitative summary of mitigation outcomes

The total mitigation outcomes from the scenarios considered in this report for 2030 and 2050 are summarised in Table 12, for both the high and low adoption assumptions for the new technologies, and relative to a range of possible reference years or periods.

Table 12. Total mitigation outcomes against the maximum and minimum efficiency baseline scenarios in 2030 and 2050 from the range of mitigation options considered in this report, for different assumptions about adoption rates for new technologies, and relative to different reference years and time periods.

	2030 vs 1990	2030 vs 2008-2012	2030 vs 2030 baseline	2050 vs 1990	2050 vs 2008-2012	2050 vs 2050 baseline
Absolute emissions						
Max baseline	28.6%	16.7%	N/A	48.6%	34.8%	N/A
Min baseline	22.2%	10.9%	N/A	32.2%	19.9%	N/A
Mitigation: high adoption of new technologies						
Max baseline	4.7%	-4.9%	-18.7%	10.7%	0.6%	-25.6%
Min baseline	0.7%	-8.5%	-17.7%	1.6%	-7.7%	-23.2%
Mitigation: low adoption of new technologies						
Max baseline	20%	9%	-6.8%	23%	11.8%	-17.3%
Min baseline	14.7%	4.2%	-6.3%	12.4%	2.1%	-15%
Emissions intensity						
Max baseline	-28.7%	-9.4%	N/A	-35.5%	-18%	N/A
Min baseline	-25.3%	-5.1%	N/A	-29.2%	-10%	N/A
Mitigation: high adoption of new technologies						
Max baseline	-43.8%	-28.4%	-21.2%	-54.8%	-42.5%	-30.1%
Min baseline	-38.9%	-22.2%	-18.3%	-47.2%	-32.9%	-25.6%
Mitigation: low adoption of new technologies						
Max baseline	-35.9%	-18.4%	-10.2%	-49.9%	-36.3%	-22.5%
Min baseline	-30.6%	-11.8%	-7.3%	-41.7%	-25.8%	-17.8%

6. Conclusions and recommendations for further work

6.1 Evaluation of baseline scenarios

We are unable to offer a single baseline scenario of future emissions going as far into the future as 2030, let alone 2050. The inability to confidently predict future emissions, and the range of potential future emissions in the absence of climate policy measures, presents a significant challenge to policy making and the setting of future emissions targets. For the scenarios developed and evaluated in this report, the spread between alternative baselines in 2030 is roughly the same if baselines are expressed as emissions intensities or in absolute emissions (about 5% difference between the maximum and minimum efficiency baseline scenarios).

However, a key difference is that changes in international market conditions could markedly affect total production (either over a finite number of years, or even in the long term) – this is not captured in the baseline scenarios used in this report, which assume essentially a single set of international market conditions. Such changes are less likely to affect emissions intensities, which would be expected to remain largely (though not entirely) unaffected by changing international market conditions. Note that the reverse may be true for the impact of droughts, where farm-level responses to droughts through accelerated culling could markedly affect apparent emissions intensities for one or several years; see Figure 9.

These considerations suggest that commitments expressed as “reductions below projected future emissions intensities” (or as further reductions below current emissions intensities) might be considered to more reliably reflect national mitigation efforts than targets based on absolute emissions This is because changes in emissions resulting from changes in livestock commodity prices or market access have the potential to significantly alter the amount of land used for different production systems and hence absolute emissions. A target based on absolute emissions could thus result either in 'hot air' being generated if targets are set high relative to historic reference levels and emissions turn out to be below projected levels even in the absence of any additional domestic climate policies. Conversely, this could result in unduly severe opportunity costs if global market demand increases but New Zealand is constrained in its ability to serve this demand due to a tight absolute emissions cap. Such outcomes cannot be ruled out entirely for intensity-based targets either, but intensity-based targets seem less prone to significant over- or underachievement solely due to international market conditions.

At the same time, it is important to recognise that emissions intensities have historically decreased for non-climate policy reasons. There is a highly plausible expectation that these non-climate pressures will continue to drive further improvements in productivity and result in further (if slowing) reductions in emissions intensities. This implies that any emissions intensity target in 2030 that reflects additional national mitigation effort will have to be set below current emissions intensities, but it is difficult to determine an appropriate level. An ambitious intensity target would need to include an accelerated rate of emissions intensity reduction, over and above that which would have occurred in the absence of climate policy. For this purpose, the baseline scenarios can represent the lower limits below which an intensity target would have to be set. The fact that we have not been able to determine a single baseline trend makes this difficult though. One option could be to set both a lower limit minimum acceptable achievement, which could be the emissions intensity of the maximum efficiency baseline, and a 'stretch' or more aspirational target based on the emissions intensity for the maximum efficiency baseline with most or all of the additional mitigation options (see Section 4) implemented. However, the choice of appropriate targets is clearly a political process and this report does not recommend any particular target, in part because it has not considered other policy measures such as price-based policies or regulations or the interaction with carbon prices for forestry or water quality policies.

It needs to be noted that there is no *a priori* reason why low emission intensities cannot be associated with low absolute emissions and that reductions in emissions intensity do not also result in reductions in absolute emissions. However, for this to happen, the rate at which product output increases has to be lower than the rate at which intensity decreases and this has not been the case so far in New Zealand. For example, reductions in emissions intensity in the dairy sector has been less than 1% per annum since 1990 but the quantity of product produced has increased by almost 5% per year over the same period (both percentages relative to the mean over 1990-2012). A fundamental assumption in this report is that the trend for New Zealand to produce large and growing amounts of product per hectare with internationally competitive estimated GHG emissions intensities will continue.

6.2 Summary of mitigation packages and implications for targets

The data presented in this report are based on our best assumptions and must be interpreted in context. The future is highly uncertain and although we have attempted to encompass some of this uncertainty in the different scenarios, our underlying assumptions have a strong bearing on the results. In particular we assume that the land area devoted to agriculture in New Zealand remains constant, dairy farming continues to expand in response to high international prices, nitrogen limits do not constrain this expansion in farming activities, current farming systems do not change radically and market conditions are such that a market for an increased quantity of New Zealand product (from all main sectors: dairy, beef and sheep) at economically attractive prices exists. With respect to the impacts of mitigation actions, additional uncertainty arises due to both efficacy and the rate of adoption of these actions. All of these factors must be born in mind when assessing the implications of our findings.

We stress that the mitigation scenarios in this report do not include mitigation outcomes from price-based climate policies (such as inclusion of agriculture in the NZ-ETS, a carbon tax, or incentives via rebates or similar measures). Such policies would both change the economics of land-use in New Zealand (particularly in interaction with a price on afforestation and deforestation) and thus could alter overall production levels as well as create incentives to adopt individual mitigation options presented in this report. While impacts on overall land-use from price-based measures have been explored by a few modelling studies, these have assumed very simplistic (mostly nil) mitigation options at the farm level. Our report suggests that this clearly is an oversimplification; an integrated analysis of the interaction between price-based climate policies, farm-level responses and land-use changes appears important to better inform climate policy decisions but was well beyond the scope of this report.

Exogenous climate shocks, such as the severe droughts of 2007-9 which had major implications for sheep populations and hence emissions, and the potential implications from climate change on the frequency and severity of droughts are also not included in our report as this would require an integrated modelling study that takes farm management responses into account, which could not be considered within the scope of this report.

6.2.1 Insights from baseline scenarios for emissions targets

Absolute emissions

- Under all baseline scenarios, absolute emissions from agriculture will continue to increase. Depending on baseline trends, emissions in 2030 would need to be reduced by 7.6-9.9 Mt to simply get back to 1990 levels and by 4.1-6.4 Mt to get back to average 2008-2012 levels. These equate to reducing emissions by 22-29% and 11-17% respectively.
- Even the most ambitious mitigation package, relative to a low-emissions baseline, does not manage to reduce emissions to 1990 levels in 2030 or beyond.
- Absolute emission estimates in our baseline scenarios already incorporate increases in the efficiency of production in line with historical trends. These already reduce emissions relative to a hypothetical case where production increases in future but efficiency remains the same; such underlying efficiency improvements are in essence 'business as usual' and we would expect them to occur in the absence of any climate driven interventions.

Emissions intensity

- Maintaining historical rates of declining emissions intensity linearly into the future appears very unlikely based on market drivers alone, even if historical rates of increasing production efficiency are maintained, due to the inevitable fall-off that occurs as production per animal rises.

- The historical record were we have robust and consistent data (1990-2012) is too short, and variability is too high, to unambiguously detect a departure from linear trends up until now. However, the emissions intensity of all sectors combined (which shows the least interannual noise) does suggest a beginning flattening out (see Figure 10).
- The historical decline between 1990 and 2012 is 1.0% per annum (relative to the mean emissions intensity for this period); this falls to 0.3 to 0.6% for the period 2015-2030, and to 0.3 to 0.5% for the period 2030-2050 in our baseline scenarios.
- Rates of decline in the beef sector could remain relatively close to historical rates, but this is mainly an artefact of the expansion of the dairy sector and the apportioning of emissions strictly by sector rather than product (i.e. the growing dairy sector effectively subsidises the apparent emissions intensity of the beef sector, if the national inventory is used as tool to calculate sector-based emissions intensities).
- Climate shocks such as drought can result in artificially low emissions intensities in some years due to high culling rates (evident especially for sheep); however, a more thorough model-based investigation would be needed to determine what the longer-term rebound effects of climate shocks could be.

The large historical multi-year variability in emissions (both absolute and intensity) means that future targets and baseline values should be based on multi-year averages or modelled reference values rather than selected individual year values. Emissions intensity tends to be more variable year-to-year, reflecting farm-level management decisions in response to price expectations and climate conditions; absolute emissions also show variability but typically over slightly longer time frames of several years. This is because absolute emissions are strongly influenced by changes in animal numbers, and these vary less readily in response to year-to-year factors as culling and re-building breeding stock is usually the response of last resort.

6.2.2 'No-cost' options – low N feed, more efficient use of N fertiliser and accelerated performance

These mitigation options are characterised loosely as 'no-cost' here because they could well occur even in the absence of targeted climate policies, as trends in this direction are already evident in the sector. This does not imply, however, that they can be accelerated ad libitum and always be no-cost, nor that their implementation does not come with real costs to farmers; it simply means that current market conditions already are creating strong incentives for moving in this direction, and hence accelerating their adoption would appear to sit well with overall industry trends and policy settings.

<u>Effect on absolute emissions</u>

- Introduction of low N feeds and increased efficiency of N fertiliser use result in reductions of 3.4-3.7% by 2030 and 6.5-7.2% by 2050 (assumed here to be feasible without affecting total production).
- Accelerated individual performance over and above the efficiency gains already assumed in the baselines, which in our scenarios occurs without any restriction on animal product or feedback on animal populations (or constraints from water quality implications) inevitably increases emissions; by 2.6-4.3% in 2030 and 3.3-8.1% in 2050 for the minimum and maximum efficiency scenarios respectively.

Effect on emissions intensity

- All of these actions result in a fall in emissions intensity, over and above the fall that already occurs in the baselines; their additive effect ranges from 2.9-5.6% by 2030 and 7.1-11.2% by 2050. These are reductions in emissions intensity relative to the emissions intensities achieved in those years in our maximum and minimum efficiency baseline scenarios.

6.2.3 'Low-cost' but unproven or not-yet commercialised options – methane vaccines, inhibitors and breeding low-emitting animals

This category of mitigation option comprises options that are not yet market ready, but where proof of concept has either already been obtained (low-emissions breeding) or where it is expected to be obtained over the next few years, with a goal of developing commercially available products by 2020. Costs from their implementation are assumed to be moderate but cannot be given reliably until commercialisation is underway.

We note that even though the low-emitting animals appear to be as productive as average animals, farmers would still face an opportunity cost from implementing this option, since the size of the gene pool available for achieving other breeding objectives would be reduced. However, the opportunity cost from this restriction has not been quantified yet.

Effect on absolute emissions

- Individually and collectively these options can have a significant effect; they are estimated to provide more than half of the total abatement potential even if their adoption remains relatively limited by 2030. For the methane vaccine and inhibitor, the amount of abatement per animal is speculative at this stage; we have assumed values based on our expert judgement and existing trials.
- The amount of mitigation, particularly for the methane vaccine/inhibitor, depends not only on the abatement per animal but also critically on the assumed rate of adoption.
- With high rates of adoption (and in conjunction with other mitigation measures considered in this report), emissions could be below average 2008-2012 levels by 2030, and even approach 1990 levels if the expansion of dairy is limited.

Effect on emissions intensity

- As for absolute emissions, individually and collectively these options can have a significant effect and would provide more than a third to more than half of the total abatement. The same caveats regarding the amount of abatement per animal apply.
- As for absolute emissions, the size of the effect, particularly for the vaccine/inhibitor depends critically on the assumed rate of adoption.
- With low rates of adoption the rate of decline in overall emissions intensity would still not achieve a linear continuation of the 1990-2012 average rate of decline. With high rates of adoption, and when combined with other mitigation options considered in this report, the rate of decline in emissions intensity could approach and even exceed the historical level of 1%, but not by much.

6.2.4 High-cost options – DCD, modified manure management with CH_4 capture

These options are characterised as high-cost either because current estimates indicate a very high cost per tonne of greenhouse gas emissions avoided (as in the case of DCD), or because they come with significant farm system changes and would require large capital investment costs, even if operational costs may be more moderate (as for the option of increased dairy animal housing and enhanced manure management with CH_4 capture).

- Despite high efficacy, the effect of DCD is minor on both absolute emissions and emissions intensity due to assumed restricted applicability, and its cost per avoided emission is high. The low overall impact on emissions applies even though we have assumed it is applied on 40% of all dairy farms during the seasons that it is effective. However, drivers for its uptake could arise from non-climate policies related to water quality; our scenario analysis suggests, however, given that its effectiveness is currently restricted by soil temperature, even an uptake on 100% of all dairy would still have only a moderate effect (in the order of 2% of total emissions from agriculture in 2030).
- Increasing the proportion of animal wastes treated in anaerobic ponds has a minor impact on absolute and emissions and emissions intensity, even when additional CH_4 emissions are 'captured', because emissions of N_2O still arise from spread manure. Revisions of emission factors could modify the absolute amounts but are very unlikely to modify this general conclusion. If CH_4 arising from anaerobic ponds is not fully captured, net emissions would increase rather than decrease from this option.

6.2.5 Implications for emissions targets

Setting emissions targets will inevitably require political judgements. The aim of this report is not to influence such judgements, but to provide information that can support the decision-making process. We reiterate that the mitigation options and outcomes presented in this report rely on a range of assumptions, and have excluded policy options that would negatively affect the economic growth aspirations of the agriculture sector.

<u>Absolute emissions</u>

- Absolute emissions from agriculture will continue to rise, making any reduction target below 1990 or 2008-2012 levels highly challenging and, based on current knowledge, impossible unless the expansion of the agricultural sector itself were constrained or new, highly efficacious mitigation technologies successfully developed and rapidly and widely adopted.
- With high rates of adoption it is possible that absolute emissions could fall below average 2008-2012 levels if all mitigation options considered in this report are indeed available and fully effective.
- The success or failure of the development of a methane vaccine/inhibitor has a large influence on the achievable emission target.

<u>Emissions intensity</u>

- Emissions intensity might appear as a more attractive metric to characterise progress as 'emissions' are seen to fall continuously. Hence any realistic future target would (and should) be expressed as significant further reduction compared to 1990 or average 2008-2012 levels.
- Even in the absence of any mitigation actions, future emissions intensity will be below historical emissions intensities.
- With mitigation, it may be possible that historical rates of reduction can be maintained or exceeded dependent upon uptake. However, large increases in the

rate of reduction of emissions intensity appear difficult, in part due to the expected declining rate of improvement in baseline scenarios.

- Since emission intensities will fall simply due to the general baseline improvements in efficiency, any target that represents climate-related efforts would need to be set below these 'natural' rates of decline. Our maximum base case could perhaps be considered as setting a minimal level of expected achievement.
- In our scenarios it should be noted that there is an inherent contradiction with regard to targets: without additional mitigation, the maximum efficiency scenario results in the lowest emissions intensity but the highest absolute emissions.

Obtaining the largest reductions in absolute emissions, and/or achieving reductions in emissions intensities that approach or exceed historical rates, relies on the availability and adoption of new mitigation technologies. This applies to any ambitious target, regardless of whether such a target is stated in terms of absolute emissions or emission intensity.

Targets expressed as absolute emissions or emissions intensity are interchangeable in this report: they rely on the same actual mitigation actions, productivity, and general assumptions. An emissions intensity target thus does not in itself imply a higher or lower level of commitment; it is the amount by which a target is below the baseline range that determines its stringency, not the way it is expressed. The main difference between an intensity and absolute target is that the former appears less prone to changes in international market conditions or domestic non-climate policy settings, and thus would appear less likely to generate either 'hot air' or result in an overly stringent commitment. On the other hand, an absolute target more directly focuses on the driver of climate change, which is the absolute amount of greenhouse gas emissions to the atmosphere.

6.3 Recommendations for further work

In this report we have been careful to point out its limitations. Below we highlight some areas of work which we feel would supplement the information presented in this report and assist in the development of evidence based policy with respect to the setting of agricultural greenhouse gas emissions targets.

- Explicit spatial modelling of the interaction between regional water quality constraints and animal populations, productivity and livestock emissions
- Improved population and productivity forecasts for each sector, taking into account potential long-run changes in market conditions and system changes rather than simply using scenarios based purely on two different assumptions about land available to livestock in New Zealand
- Modelling of sector responses to price-based policies that take actual mitigation options into account, to better understand sector responses in absolute emissions and emissions intensity and their interaction with land-use change
- Global scale outcomes of increased/reduced production and efficiency in NZ to better support a potential policy choice of setting an intensity-based target
- Modelling performance and Stocking Rate independently, along with economic performance to look at best balance between absolute emissions, emissions intensity and profitability within a given quantity of production. The approach used here means that changes designed to reduce intensity (higher individual

performance along with a fixed Stocking Rate) will automatically increase absolute emissions and this should not be taken as the only available option.

- Greater effort needed to estimate N content of diet & how it is changing as it looks to be an easy low/no cost way of reducing emissions. It is probably already happening but we don't capture it in the current inventory.
- Better quantification of emissions from waste – waste applied to pasture and CH_4 from waste storage systems. There is high uncertainty over net benefits of housing-stand-off pads. These becoming more common and current inventory indicates they have a negative rather than the claimed positive effect on N_20 emissions although they may have positive benefits for N leaching.
- Incorporation of variable exogenous shocks into the modelling. For example, year to year price variability and its effect on achieved physical performance and the effects of drought, including in the context of a changing climate.
- Incorporate more flexibility in the inventory reporting tool. It is an excellent tool for reporting an annual inventory but the inability for some parameters to change with time place limitations on scenario development and assessment.
- Back-casting and decomposing efficiency trends to better understand future options. Improved efficiency looks to be the most reliable way of decreasing emissions intensity (especially if starting from a relatively low-efficiency baseline) although unless very high values are assumed for the increase in individual animal performance the rate of improvements in emissions intensity will decline. Have many of the easy wins been already achieved? A more detailed examination of the intensity-performance relationship for the different sectors is warranted, also to better understand policy design to accelerate emissions intensity improvements.