Farmer inputs and verification options for He Waka Eke Noa emissions reporting

Tony van der Weerden, Cecile de Klein, Robyn Dynes, John McEwan and Ronaldo Vibart

August 2021

Report for He Waka Eke Noa

Client Report Number RE450/2021/056

agresearch
āta mātai, mātai whetū

Contents

Executive Summary

It is in the interests of all agricultural sectors, government and iwi that agricultural greenhouse gas (GHG) reporting by farmers is as simple but as accurate as possible. Recently we proposed input specifications for Intermediate and Detailed methods for on-farm GHG reporting (van der Weerden et al. 2021). The purpose of this report is to:

1. Simplify these methods, where practical, whilst retaining the ability to capture the current and potential mitigation strategies associated with the methods.
2. Assess the availability and ease of verification/auditing of the inputs required for the (revised) Intermediate and Detailed methods, through consultation with farmer and industry experts.

We revised the Intermediate method so that it now only requires six inputs. However, as a result of this simplification, it can no longer capture on-farm efficiencies for livestock systems. Of the six inputs identified, only four are essential for completing a GHG calculation:

1. Farm area,
2. Stock reconciliation (animal numbers and time on farm), split by stock class,
3. Milk, meat, wool and velvet production,
4. Total synthetic N fertiliser by type.

Two remaining inputs are not essential, however, the first (method of application of synthetic N fertiliser) provides cropping farmers to be recognised for lower ammonia emissions, an indirect source of nitrous oxide (N_2O). The second relates to the area of the farm in different slope classes, which provides farmers with the opportunity to account for lower GHG emissions due to sloping land (reduced direct N_2O emissions from urine). Although information on slope class is currently not held on many farms, this data is increasingly available from a range of sources for a small, one-off financial cost.

The Detailed method for livestock enterprises requires 10-12 inputs, most of which are essential to capture on-farm efficiencies and mitigations from improved animal genetics, forage type and optimised management.

The table below provides a summary of the required inputs, their availability now or in the future, the relative time and cost for collating the data, and ease with which farmers can supply the data for auditing and verification. Approximately one third of the farm inputs for the Detailed method are unlikely to be readily available/recorded at present. However, in most cases farmers could begin to record these inputs in farm diaries and farm management software (if already used) at no cost.

Farmer feedback suggested the time required to collate each input was typically less than 10 hours per annum. For several inputs the recording of farm information may be as few as 1-2 hours per annum. Furthermore, efficiencies in data recording can be gained when collating multiple inputs at the same time and by using farm management software that retain data entries from previous years. The time required to record and collate all inputs for a livestock farm will therefore depend on whether farmers are recording information in a farm diary or using farm management software. Farm type and method of GHG calculation will also influence the annual time required:

- For dairy farmers, the majority of required data for the revised Intermediate and Detailed method are already collected to meet requirements of milk processors. It is estimated that

an additional 5 hours per annum would be required to record and document additional data (stock class information) for the Intermediate method, while the Detailed method may require approximately an additional 10 hours per annum to record and document stock class information, supplement use and time spent grazing on different forages.

- For drystock farms, it is estimated that farmers would require 10 to 60 hours per annum to record the data required for the revised Intermediate method and between 50 and 100 hours per annum for the Detailed method. Body weights at multiple times of the year was considered the most challenging input for many farmers to record.

- For non-livestock cropping farmers and vegetable growers, the time required to collate fertiliser data for the Detailed method is estimated at approximately 5 hours per annum, with less time required for an Intermediate method.

It will be relatively simple for farmers to supply the required data for auditing and verification for most inputs, utilising data captured in tax returns, meat and milk processing companies, farm management software, dairy company annual reporting requirements, the National Farm Assurance programme and fertiliser records. As was the case for data collection, body weights at multiple times of the year may also be the most challenging input to audit and therefore may require verification from weights of culled livestock on processor kill sheets or sales records.

Technological solutions for auditing and verification exist, including geo-tagged photos and GPS-enabled smart collars on livestock. One future may see all livestock tagged with ultra-high frequency (UHF) radio frequency identification (RFID) to monitor stock numbers and weights, and location and movement on farm. This would provide farmers with critical information to potentially improve on-farm operations and management, and supply farm data for a Detailed GHG calculation with minimal input from the farmer. This could provide a simpler yet more accurate method for supplying data for auditing and verification, although the capital and time investment by business owners is noted.

Summary of availability and cost of collating farmer inputs for different GHG calculation methods

Method of GHG calculation and associated farmer inputs	Readily available now	Readily available future	Addition al time per annum	Additional external direct cost	Ease of supplying data for verification & auditing
***Revised* Intermediate**					
Farm area	Highly likely	Highly likely	< 10 hrs	Nil	Simple
Stock reconciliation	Likely	Highly likely	< 10 hrs	Nil	Simple
Milk, meat, wool and velvet production per animal type and class	Highly likely	Highly likely	< 10 hrs	Nil	Simple
Area of farm in different slope classes [1]	Unlikely	Likely	< 10 hrs	$10s-$1000s[2]	Simple
Annual synthetic N fertiliser by type	Highly likely	Highly likely	< 10 hrs	Nil	Simple
Synthetic N fertiliser application method (cropping/vegetables production only)	Likely	Highly likely	< 10 hrs	Nil	Simple
***Revised* Detailed**					
Farm area	Highly likely	Highly likely	< 10 hrs	Nil	Simple
Monthly/quarterly animal number by stock class & age	Likely	Likely	< 10 hrs	Nil	Simple
Quarterly/key farm operations animal number by body weight	Unlikely	Likely	10-50 hrs	Nil	Challenging
Time & animal numbers on off-paddock facilities	Unlikely	Highly likely	< 10 hrs	Nil	Simple
Date of start and end of grazing of different feed types	Likely	Highly likely	< 10 hrs	Nil	Simple
Imported feed	Likely	Highly likely	< 10 hrs	Nil	Simple
Planned start of mating	Highly likely	Highly likely	< 10 hrs	Nil	Simple
Weaning/post-weaning percentages	Highly likely	Highly likely	< 10 hrs	Nil	Simple
Milk, meat, wool and velvet production per animal type and class	Highly likely	Highly likely	< 10 hrs	Nil	Simple
Area of farm in different slope classes[1]	Unlikely	Likely	< 10 hrs	$10s-$1000s[2]	Simple
Effluent/manure application method	Likely	Highly likely	< 10 hrs	Nil	Simple
Monthly synthetic N fertiliser by type	Highly likely	Highly likely	< 10 hrs	Nil	Simple
Synthetic N fertiliser application method (cropping/vegetables production only)	Likely	Highly likely	< 10 hrs	Nil	Simple

[1] non-essential input for calculating GHG emissions but provides farmers with the option to account for the effect of slope class on N_2O emissions from livestock urine (slope class). [2] One-off cost, not annual.

1. Background

Following on from the completion of the 'Input specifications for He Waka Eke Noa reporting methods' report (van der Weerden et al. 2021), the He Waka Eke Noa Emissions Reporting Working Group would like to assess the following aspects in relation to the greenhouse gas (GHG) reporting methods:

1. How could the Intermediate method and associated farmer inputs be further simplified, whilst retaining the ability to capture the mitigation strategies aligned with this method?

2. How easy will it be for individual farmers to source each input required for the revised Intermediate and Detailed methods for calculating GHG emissions (i.e., how available is the information based on current farming practices and, if not available now, what would be involved in sourcing this information in future)?

3. How could each of the inputs for the revised Intermediate and Detailed methods be supplied for auditing or verification after emissions are reported into an accounting system?

2. Approach

To meet He Waka Eke Noa's requirements outlined in Section 1, we have provided the following information:

1. Tabulated minimum requirements for inputs for the most simplified version of the Intermediate method that ensures this *revised* version can still capture mitigation options aligned with the previous Intermediate method. Commentary on what is lost when this simplified approach is taken, and potential variants from the simplest version that may have useful advantages at little extra cost or effort, e.g., accuracy or incentives.

2. Input information that is or is not currently collected by farmers. For information not currently collected, indicative hours, indicative external costs, and suggested sources of information for the (simplified) Intermediate and Detailed methods will be provided. This step was conducted in consultation with 16 farmers (including representatives of the He Waka Eke Noa farmer reference group) across all sectors (see Appendix 4), and with representative agritech companies.

3. Tabulated potential methods for supplying farmer input data for auditing and verification purposes. This includes existing and potential future methods, which have been discussed with farmers to ensure the proposed methods are achievable.

Farmer inputs and verification in relation to carbon (C) sequestration were not in scope for this report.

3. Minimum requirements for revised Intermediate and Detailed methods

We have simplified the Intermediate method by replacing farm-specific data on animal body weight and lambing and calving percentages with industry averages for reproduction and liveweight gain (Table 1). These industry averages would be applied to different stock classes used by the drystock and dairy industries (e.g. hogget, two-tooth ewes, heifers Rising 1 year of age (R1), stags R1, male 1 year+ goats) or breeds (e.g. Jersey, KiwiCross, Holstein-Friesian). The revised Intermediate method is easier for farmers to complete, however, some of the accuracy of the GHG calculations for individual farms has been reduced. Employing industry averages for body weight and lambing and calving percentages rather than on-farm actuals does not allow farmers to capture on-farm animal physiology efficiencies. For example, drystock farmers will not be able to capture any livestock efficiencies and investment in improved genetics, such as breeding ewes that produce more lambs at the same mature body weight or ewes of lower body weight weaning a greater weight of lambs. Drystock farmers wishing to capture these on-farm efficiencies will be required to use the Detailed method for their GHG calculations.

It is important to note that while the revised Intermediate method is simpler than the original Intermediate method, it is still more detailed than the original Simple method. For instance, by separating stock by classes, the farm-scale GHG calculations will be more accurate than emissions based purely on the number of sheep or cattle, without any regard for the age and size structure of the flock or herd. Similarly, using farm production data (milk, meat, wool, velvet) instead of industry averages will increase the accuracy of the farm-scale GHG calculation.

While not part of the original project scope, we also identified several areas where the Detailed method could be revised to simplify the process for farmers collating relevant data and/or to improve the accuracy of the GHG footprint calculation (Table 2). These revisions relate to livestock characteristics and forage grazing, which enable more accurate estimates of enteric methane (CH_4) emissions. Detailed GHG calculations would utilise these revised inputs to determine energy and dry matter (DM) requirements for different stock classes at specific times of the year, based on body weights, reproduction data, production data and forage types. Due to the Detailed method requiring more inputs to calculate livestock energy and DM requirements, submitters of data for farm-scale GHG calculations will need to select whether they are completing an Intermediate or Detailed approach. We recommend that if there is an insufficient number of farm inputs available for calculating the energy requirements of stock, then the submitter may be required to complete an Intermediate-level calculation. We also recommend that the GHG calculator should be sufficiently flexible to allow farmers to separately select between a revised Intermediate and Detailed method for either livestock or fertiliser. For example, a farmer should be able to conduct a Detailed livestock calculation and an Intermediate fertiliser calculation. A description of the differences between the revised Intermediate and Detailed methods can be found in Appendix 1.

Mitigation options associated with the original and revised Intermediate methods are the same, apart from one change (Table 3). Following discussion with researchers involved in the low CH_4 sheep research programme, low CH_4 sheep and cattle will now be captured as a mitigation strategy in the revised Intermediate approach by applying a percentage reduction to default CH_4 emissions per head for each stock class. This is slightly different to the Detailed method, where a percentage reduction in CH_4 emission will be applied to the CH_4 emissions per kg DM intake (DMI). Low CH_4 emitting sheep are not yet available as a mitigation option to all farmers as the breeding value for this genetic trait has yet to be fully integrated into the genetic evaluation in Beef + Lamb Genetics.

Table 1: Suggested simplification of Intermediate method, including justification.

Method component	Intermediate (original)	Intermediate (revised)	Justification
Farm area	*Absent*	Farm area	Required for determining GHG footprint per hectare. Total vs. effective area has yet to be determined by He Waka Eke Noa at the time of writing.
Number of animals	Animal numbers split by category (body weight, species and physiological status (i.e. maintenance vs lactation vs. growth))	Stock reconciliation (animal numbers, time on farm, stock sales and purchases and stock deaths), split by stock class/breed[1]	The revised stock reconciliation requires the opening and closing numbers by stock class (e.g. hogget, two-tooth ewes, heifers R1), time on farm, weaning numbers, stock sales and purchases (numbers and weights), and stock deaths. Reproduction and liveweight gain to be derived from appropriate industry data[2]. For dairy, farmers will be required to select the animal breed to determine average annual liveweights. Farmers wishing to capture on-farm livestock efficiencies can use Detailed method. The GHG calculator will be required to determine weighted annual number of stock using dates entering and exiting farm.
Animal reproductive data	Lambing and calving percentage	*Removed*	
Animal production	Milk, meat and wool production per animal type and category	Milk, meat, wool and velvet production per animal class[3]	*No change*
Topography[4]	Area of farm in different slope classes (flat/low slope; medium/steep slopes)	Area of farm in different slope classes (flat/low slope; medium; steep slopes)	*No change*
Fertiliser type	Total synthetic N (product tonnage) split into urea, non-urea, urea + urease inhibitor	Total synthetic N (product tonnage) split into urea, non-urea, urea + urease inhibitor	*No change*

Fertiliser application method	Surface or incorporation	Surface or incorporation	*No change*

[1] this requires knowing the number of stock per class (drystock) or breed (dairy), including stock movements. See Appendix 2 for stock classes/breeds

[2] sources for reproduction, liveweight gain and production data include Beef + Lamb New Zealand sheep and beef farm surveys and DairyNZ Facts and Figures. Methods of calculation (e.g. lambing/weaning percentages) should align with those used by industry bodies.

[3] Meat and wool production will be at lower granularity (e.g. meat from lambs, hoggets, mature ewes) compared to stock classes shown in Appendix 2

[4] non-essential; if not available, then assume flat/low slope. If available, GHG calculations must include modelling of nutrient transfer of urine-N from steep to lower slopes.

Table 2: Suggested revision of Detailed method, including justification.

Method component	**Detailed (original)**	**Detailed (revised)**	**Justification**
Area of farm	*Absent*	Area of farm	Required for determining GHG footprint per hectare. Total vs. effective area has yet to be determined by He Waka Eke Noa at the time of writing.
Number of animals	Monthly animal number split by category (body weight, body weight changes, species, age and physiological status (i.e. maintenance vs lactation vs. growth)) including time off paddock	Dairy: Monthly milking cows, dry cows, replacements and breeding bulls on farm, including time on off-paddock facilities. Cow liveweight at 4-5 months after planned start of calving (most farms at 1 December); if unknown, then breed is required[1]. Proportion of year that young stock are on-farm. Drystock: Monthly/quarterly animal number split by stock class[1], age & body weight	Dairy: Class of young stock can align with liveweight of mature cow, with annual DM requirements calculated from the average annual liveweight of the dairy herd and proportioned for the number of months on farm after weaning. Young stock and dry cows – time on farm will be required if point of obligation sits with landowner but will not be required if point of obligation sits with business owner (still to be determined). Some drystock farmers may find it too challenging to collect monthly data on numbers and body weights. Also, sheep, beef and deer farmers may find it easier to collect data at key farming operations (mating, scanning and weaning). Alternatively, stock class could be used to obtain regional industry averages for body weight. Body weight gain removed, as this could be estimated from body weights and dates on/off farm within GHG calculator. Physiological status removed as it will be captured by class and more detailed reproductive data.
Feed type eaten	Monthly feed type per animal category	Date of start and end of grazing of different feed types Introduced a new input called 'Imported feed' to capture data	Farmer feedback suggested monthly data would be challenging for some, therefore input altered to dates stock moved from one forage type to another, bearing in mind that for some crops a transition period will be required. The GHG calculator needs to include a 'dropdown' list of different pastures and forages (e,g, brassicas, beets, plantain, etc.)

		on imported supplements fed to dairy cows and drystock grazing on farm (type, amount, wet weight vs dry weight, feeding method) and total milk powder purchased for calves	and default feed quality values. For non-pasture, users should be able to over-ride default feed quality data with farm-specific data. For dairy, energy, DM and N intake from supplements and forages required to determine CH_4 emissions and N excretion. GHG calculator needs to include supplement database and percent utilisation for feeding method. Energy calculation should include default change in body condition score over lactation season. It is assumed that replacements (17-27% of herd) are fed purchased milk powder. Further research is required to determine the significance of this activity on the total farm GHG calculation – see 'Future Research' (section 4.3).
Animal reproductive data	Breeding date, pregnancy date, lambing percentage, culling date	Planned start of mating; lamb, beef and deer weaning percentage; number of replacements retained post-weaning; number of other stock (carry-over/bulls etc)	More detail included to provide a more accurate assessment of energy requirements. This will have a direct impact on enteric CH_4 (largest GHG source). To improve this assessment for dairy, dairy calf weaning date can be assumed to be 4 months after planned start of calving.
Animal production	Milk, meat and wool production per animal type and category	Milk, meat, wool and velvet production per animal type and class[2]	*No change, however, for milk production this should include milk solids, litres, protein and fat.*
Farm location	Required[3]	Required[3]	*No change*
Topography[4]	Area of farm in different slope classes (flat/low slope; medium; steep slopes)	Area of farm in different slope classes (flat/low slope; medium; steep slopes)	*No change*

Method component	Detailed (original)	Detailed (revised)	Justification
Type of manure stored & applied to land	Effluent, solid manure, slurry	*Removed*	No longer required, as this is now acknowledged to be challenging for farmers to estimate. Time on specific types of off-paddock facilities should provide sufficient information to estimate manure type: see 'Future Research' (section 4.3).
Effluent/manure application method	Surface or incorporation	Surface or incorporation	*No change*
Fertiliser type	Monthly total synthetic N (product tonnage) split into urea, non-urea, urea + urease inhibitor	Monthly total synthetic N (product tonnage) split into urea, non-urea, urea + urease inhibitor	*No change*
Fertiliser application method	Surface or incorporation	Surface or incorporation	*No change*

[1] this requires knowing the number of stock per class (drystock) or breed (dairy), including stock movements. See Appendix 2 for stock classes/breeds

[2] Meat and wool production will be at lower granularity (e.g. meat from lambs, hoggets, mature ewes) compared to stock classes shown in Appendix 2

[3] If the method includes an algorithm for estimating N_2O EF for urine based on soil and climate; also useful if spatial N leaching factors can be developed.

[4] non-essential; if not available, then assume flat/low slope. If available, GHG calculations must include modelling of nutrient transfer of urine-N from steep to lower slopes.

Table 3: Summary of mitigations captured (and required adjustments to the required GHG calculations) in the revised Intermediate and Detailed methods.

Mitigation availability	Revised Intermediate	Revised Detailed
Current		Low CH_4 forages (adjusted CH_4 EF per kg DMI)
		Low N_2O forages (adjusted N excretion per animal type, age and sex; adjusted N leaching factor)
	Urea + urease inhibitor; Fertiliser incorporation (adjusted ammonia loss factor)	Urea + urease inhibitor; Fertiliser and manure incorporation (adjusted ammonia loss factor)
In Progress	Low CH_4 sheep (BV) (adjusted CH_4 emissions per head*)	Low CH_4 sheep (BV) (adjusted CH_4 EF per kg DMI*)
Future	Low CH_4 sheep (vaccines/inhibitors), low CH_4 cattle (vaccines/inhibitors/BV) (adjusted CH_4 emissions per head*)	Low CH_4 sheep (vaccines/inhibitors), low CH_4 cattle (vaccines/inhibitors/BV) (adjusted CH_4 EF per kg DMI*)
		Low N_2O cattle (adjusted N excretion)
	Nitrification inhibitors (adjusted N_2O EF and N leaching factor for urine and dung, manure application and N fertiliser)	Nitrification inhibitors (adjusted N_2O EF and N leaching factor for urine and dung per forage type; for manure application and N fertiliser)
	Effluent ponds - CH_4 flaring to CO_2; CH_4 biogas harnessing for energy source (adjusted amount of CH_4 emitted).	Effluent ponds - CH_4 flaring to CO_2; CH_4 biogas harnessing for energy source (adjusted amount of CH_4 emitted).
	Covered manure stores (adjusted ammonia loss factor)	Covered manure stores (adjusted ammonia loss factor)

* BV (breeding values) for low CH_4 are recorded as percentage reduction in CH_4 emitted per head; research BV on this basis currently available for sheep, but has yet to be fully integrated into the genetic evaluation in Beef + Lamb Genetics: estimated completion 2022. The low CH_4 BV integrate the effect of low CH_4 per kg DMI and increased feed efficiency (less DMI per unit of production). For detailed methods, the proposed approach for capturing low CH_4 sheep in GHG calculations is to convert BV to an adjusted CH_4 emitted per kg DMI. In future, BV may be separated into an adjusted CH_4 and increased feed efficiency.

4. Input information and auditing/verification options for revised Intermediate and Detailed methods

Farmer input information and auditing and verification options for the revised Intermediate method and revised Detailed methods are shown in tables 4 and 5, respectively. For each input, we have indicated whether the data is readily available now, and if not, whether it would be readily available in the future. We have also suggested sources of information, along with an indicative time (ranging from <10 hours to 50-100s of hours per annum) and external cost (from no cost to $100s) for data collection. This information was based on consultation with dairy, sheep & beef, deer and cropping farmers, fruit and vegetable growers, industry representatives, agritech companies and consultants and. Details on the sources of input information and any associated challenges are given in Section 4.1.

A robust and credible auditing and verification process will be required for farmer input information. In consultation with farmers, industry representatives and agritech companies, we have explored current and future methods for ensuring information provided by farmers for the revised Intermediate and revised Detailed methods can be independently audited or verified (Tables 4 and 5, respectively; Section 4.2). This included an assessment of the ease of supplying auditable and verifiable farm data to auditors by farmers (simple, challenging).

Appendix 3 outlines some of the farm management software tools that allow farmers to capture farm information while Appendix 4 lists suggestions from farmers for ensuring the GHG reporting process is made simple.

4.1 Sources of input information and associated challenges

Farmer information for the revised Intermediate method is limited to a maximum of six inputs: (i) area of the farm, (ii) stock reconciliation by stock class, (iii) production data, (iv) area of farm in different slope classes, (v) total synthetic N fertiliser use and (vi) amount of fertiliser surface applied or incorporated (see Section 4.1 and Table 4). Most of this data is readily held by farmers in their farm records. Of these inputs, only four are essential for a GHG emission calculation: farm area, animal numbers split by stock class, production data and total synthetic N fertiliser use; while N fertiliser method of application is available to cropping farmers who want to account for fertiliser incorporation as a mitigation option (the default setting would assume no fertiliser incorporation). It should be noted that fertiliser incorporation within a typical cropping or horticultural system will have a relatively modest effect on a GHG calculation. The remaining input (farm slope classes) is not essential to calculate emissions or to account for mitigations. However, it does provide farmers with the opportunity to account for lower GHG emissions due to sloping land (reduced direct N_2O emissions).

Pastoral farmers using the revised Detailed method will require 10-12 inputs (see Section 4.1 and Table 5). Farmer feedback suggested the time required to collate each input was typically less than 10 hours per annum (as opposed to 10-50 hours, or more). However, for several inputs the recording of farm information may be as little as 1-2 hours per annum. Furthermore, efficiencies in data recording can be gained when collating multiple inputs at the same time.

The time required to record and collate all inputs for a livestock farm will depend on whether farmers are recording information in a farm diary or using farm management software. Farm type and method of GHG calculation will also influence the annual time required. For dairy farmers, the majority of required data for a revised Intermediate and Detailed method are already required for milk processors. It is estimated that an additional 5 hours per annum would be required to record and document additional data (stock classes information) for the revised Intermediate method, while the Detailed method may require approximately 10 hours per annum to record and document stock class information, supplement use and time on different forages. To record and document the required data for a drystock GHG calculation, it is estimated that farmers would require 10 to 60 hours per annum to record the data required for the revised Intermediate method and between 50 and 100 hours per annum for a Detailed GHG method. For non-livestock cropping farmers and vegetable growers, the time required to collate fertiliser data for a Detailed method is estimated at approximately 5 hours per annum, with less time required for a revised Intermediate method. Further efficiency in data recording can be gained for farmers that use farm management software, as this will retain previously entered data, thereby reducing the time required for updating data after year 1.

Revised Intermediate

1. Farm area

Area of farm will be required for calculating GHG emissions per hectare. 'Area' could relate to total or effective grazing area; the definition has still to be determined at time of writing. If effective area is required, there will be a cost for some farms if a GPS map is required to determine the area of all the legal titles (total area) and area in pasture or crops (effective area).

2. Stock reconciliation split by stock class

Most if not all farmers will have data on livestock numbers per class of animal, as this information is required for farm accounts and annual submission to the Inland Revenue Department as livestock reconciliations. For livestock on farm for less than 12 months, farmers will be required to include date of farm entry for mobs purchased and sales to allow a calculation of weighted annual averages. For red meat, stock sales and purchases, as well as kill sheets from meat processing companies will also provide information on timing and number of stock slaughtered. The same data sources could be used for validation. Dairy farmers will be required to select the animal breed to determine average annual liveweights – see Appendix 2 for six breed/crossbreed options. Weights of replacements will not be required as these can be based on herd genetics; only the time on farm must be recorded (if the point of obligation lies with the landowner). The GHG calculator will require default energy intake for replacements. For any breeds not included, farmers should select a proxy from one of the three Jersey/Friesian crossbred options. Default pasture quality data (ME, N content) will be required in the GHG calculator to determine DM and N intake by grazing livestock.

3. Milk, meat, wool and velvet production per animal type and class

Production data is available from processors, stock sales records, grazing contracts and tax returns: this could be used as a data source and for auditing purposes. Livestock which increase in weight but are not sold or finished within a financial year will be counted in a livestock reconciliation, with industry average weight changes used for estimating energy requirements. However, wool is a product that can be carried over from one year to the next, particularly when prices are low, which suggests there may be some error within a single year.

4. Area of farm in different slope classes

Recent research has shown that N_2O emissions from urine patches are lower from soils on steeper slopes compared to low slopes, and emission factors have been established for different slope classes for dairy and non-dairy cattle, sheep and deer (van der Weerden et al. 2020). Farmers wanting to capture this slope class effect will require verified information on the proportion of the farm at different slopes (< 12°, 12 - 24°, > 24°). Farmers are unlikely to have information on slope classes across a farm, therefore this information may need to be purchased as a one-off cost from a suitable mapping company where costs may range from hundreds to thousands of dollars. Several fertiliser companies and farm management software companies can also provide this service, and, depending on the relationship/agreement between farmer and company, costs are estimated to range from tens to several hundreds of dollars.

5. Annual synthetic N fertiliser by type

Annual data is readily available through annual farm accounts and fertiliser suppliers. Synthetic N fertiliser should be split into standard urea, urease-inhibitor treated urea, and non-urea N fertiliser, due to different N emissions from each category. The recent N fertiliser cap for pastoral farms requires reporting of annual synthetic N fertiliser usage, this could be used for the GHG emission calculations. To simplify the data collation process for farmers, fertiliser companies could provide data on the amount of N sold to farmers on the basis of standard urea, urease-inhibitor treated urea, and non-urea N fertiliser. Auditing of annual fertiliser data could be achieved using fertiliser supplier accounts.

6. Synthetic N fertiliser application method (cropping/vegetable production only)

This input is specific to cropping farmers. It is unlikely that cropping farmers will maintain formal records on method of fertiliser application. However, this could be either sourced from own farm records or from information provided by contractors (e.g. type of drill used, such as Cross slot, where fertiliser is placed beneath the surface near the seed). If data is not available, the GHG calculator will assume synthetic fertiliser is surface applied.

Revised Detailed

1. Farm area → Same as Revised Intermediate - see above

2. Monthly/quarterly animal specific data, including reproduction

Class and age; body weight; planned start of mating; lamb, beef and deer weaning percentage; number of replacements retained post-weaning, number of dry cows

Farmers will have most of these animal data on-hand at the stock class level, either captured in farm records or in farm management tools (see Appendix 3). The most challenging data for farmers to collect will be body weights at different times of the season. Data on quarterly body weights are unlikely to be readily available and farmers from all the main livestock sectors note significant complexity in providing this data, including the need for suitable weigh scales. Farmers interviewed indicated the number of farms with weigh scales is very low (e.g. for sheep it is estimated <30% of the national flock and <1% of farms have weigh scales). For farms without sufficient weight data, it will be challenging to collate body weight data at different times of the season.

For drystock farmers, options include:

2.1 Body weights may be estimated from back-calculation of annual data, based on meat processing kill sheets. However, to determine weight of mature ewes/cows, this would require data calculated from kill sheets from processing of cull animals. Culled carcass weights should undergo a sense check to determine if these are representative of the flock/herd, given they may be slaughtered at either heavier or lighter weight than flock/herd average. Weights estimated from kill sheets based on their lightest weight may disadvantage farmers who weigh stock on farm with scales. Weights may also be estimated from sales records, although this option was not favoured by farmers.

2.2 Rather than providing monthly body weight data, quarterly data appear to be more feasible for drystock farmers. The data would be captured at the time of normal yarding operations (e.g. at mating (Feb-April), scanning (May-July) and weaning (Oct-Dec), from which changes in energy requirements throughout the season could be estimated. Finishers are likely to collect this data, whereas breeders are unlikely to hold these records. It is possible that at the time of pregnancy scanning, the contractor could also capture body weights of all animals scanned. With mature aged stock (e.g. mixed aged ewes), a sensitivity analysis should be under-taken to determine the added accuracy of moving from a constant body weight (i.e. annual body weight) to calculating emissions based on quarterly body weights (see section 4.3).

2.3 In lieu of back-calculated body weights or weights captured at the time of normal yarding operations, industry regional and farm class averages for specific breeds may be required to generate the required inputs.

For dairy farmers, monthly cow numbers are required by most milk companies. Average body weight can either be derived from breed or from weighing the entire herd 4-5 months from planned start of calving (for most farms this will be around 1 December). Along with MS production data, this provides a suitable source of data for determining energy requirements for the milking herd.

The challenge for drystock farmers to record and collate body weight data may also relate to the auditing process. Auditing options include meat kill sheets, farm management tools and back calculation of data from annual stock reconciliation from tax accounts. For dairy, the supply of data to auditors will be relatively simple, compared to drystock, as the data entered into DairyBase (monthly cow numbers, weights on 1 December, or selected breeds with associated average weights) should meet the auditing requirements.

3. Time & animal numbers on off-paddock facilities

Farmers are currently unlikely to keep farm records of the number of animals and duration on off-paddock facilities (e.g. feed pads, stand-off pads, animal shelters, free-stall barns). However, for dairy, this information is being requested by most milk companies thus is readily available.

4. Date of start and end of grazing of different feed types

We originally suggested farmers could collate monthly information on the type of feed eaten by each class of livestock. However, within each of the sectors, farmers interviewed had contrasting views on the capacity to collect this data. For some, it was complex and challenging to report from existing records, while others suggested it was highly likely they could provide that data. To ensure collection of information is as simple as possible while still being able to capture the benefits of demonstrating low GHG forages used on farm, we have altered the required information to the date stock enter and exit different forage types bearing in mind that for some crops a transition period will be required. This information can then be integrated with stock numbers and weights to match energy requirements with energy supply from the different forage types to calculate DM intakes across the year. Farmers would be required to maintain dates of stock on different forage types in farm records (e.g. farm diaries, farm management tools (Appendix 3)). As for the revised Intermediate method, default pasture quality data (ME, N content) will be required in the GHG calculator to determine DM and N intake by grazing livestock. For crops, defaults values should be provided, with the option for submitters to over-ride defaults with measured values. Records of crop feed quality will need to be documented and stored for auditing purposes. It may be difficult to audit pasture quality farm data due to the extensive use of pastures and potential difficulty in auditing the quality of the pasture used for grazing.

5. Imported feed

For dairy and drystock farmers using imported supplements, the type, amount (including whether amount is based on dry weight or fresh weight) and feeding method will be required. For dairy farmers, this information is captured by most milk companies and in DairyBase (although not many farms use DairyBase). Dairy farms may also purchase milk powder for calves up until weaning – the significance of this imported feed on farm-scale GHG emissions requires investigation (see section 4.3). The GHG calculator will need to include a supplement and milk powder database on feed quality and percent utilisation based on the feeding method. Utilisation data can be sourced from Dairy NZ.

6. Milk, meat, wool and velvet production per animal type and class → Same as Revised Intermediate - see above

7. Area of farm in different slope classes → Same as Revised Intermediate - see above

8. Effluent/manure application method

This is specific to cropping farmers and vegetable growers where manure can be incorporated at the time of application or immediately following surface application. It is unlikely that cropping farmers will maintain records on method of application per volume of manure. However, this may be relatively easy to collect, either calculated from own farm records or from information provided by contractors (e.g. proof of placement documentation, which will be influenced by the type of manure spreader and/or timing and type of cultivation). If data is not available, the GHG calculator will assume effluent/manure is surface applied.

9. Monthly synthetic N fertiliser by type

As for annual data, monthly data should be available through farm accounts and fertiliser suppliers. Synthetic N fertiliser should be split into standard urea, urease-inhibitor treated urea, and non-urea N fertiliser, due to different N emissions from each category. It may also be possible to develop temporal N leaching factors, which will improve accuracy of indirect N_2O emissions. As noted above for ‘annual’, to simplify the data collation process for farmers, fertiliser companies could provide the monthly amount of N sold to farmers on the basis of standard urea, urease-inhibitor treated urea, and non-urea N fertiliser. Auditing of fertiliser data could be achieved using fertiliser supplier accounts.

10. Synthetic N fertiliser application method (cropping/vegetable production only) → Same as Revised Intermediate - see above

Table 4: Input information for revised Intermediate method, including sources of information and ease and potential methods for verification/auditing. Note: ratings for ease of supplying suitable data for verification/auditing = simple, challenging.

Input information	Readily available now?	Readily available in the future?	If not, indicative hours for collection	If not, indicative external cost for collection	Potential sources of information	Ease and source for supplying suitable data for verification/ auditing	Notes/comments, including GHG requirements
Farm area	**Highly likely**	**Highly likely**	**<10 hours**	**Nil**	Farm accounts for valuation/taxation	**Simple**	If effective area is required, there may be a cost to the farmer for mapping pasture and crop areas
Stock reconciliation split by stock class	**Likely**	**Highly likely**	**<10 hours**	**Nil**	Farm accounts for valuation/taxation; meat company kill sheets. Dairy cattle: Monthly data required for most milk processors; also recorded in MINDA	**Simple** Farm accounts for valuation/taxation; meat company kill sheets	The GHG calculator will be required to determine weighted annual number of stock using dates entering and exiting farm.
Milk, meat, wool and velvet production per animal type and class	**Highly likely**	**Highly likely**	**<10 hours**	**Nil**	Milk processing plants; Meat company kill sheets; DeerPro (for deer); Wool merchants	**Simple** Tax returns Milk supply reports; Meat company kill sheets; DeerPro (for deer); Wool merchants	IRD returns may not capture all wool on-hand – can be carried over from one year to the next. In-shed technology (dairy) provides a check of processors' data. Liveweight gain of young stock retained must be calculated/estimated.

Input information	Readily available now?	Readily available in the future?	If not, indicative hours for collection	If not, indicative external cost for collection	Potential sources of information	Ease and source for supplying suitable data for verification/ auditing	Notes/comments, including GHG requirements
Area of farm in different slope classes	**Unlikely**	**Likely**	**<10 hours**	**$10s-$1000s**	Farm mapping services; major fertiliser companies	**Simple** Farm mapping services; major fertiliser companies	One-off requirement; non-essential but enables farmers to capture effect of slope class on N_2O emissions
Annual synthetic N fertiliser by type split into urea, non-urea, urea + urease inhibitor	**Highly likely**	**Highly likely**	**<10 hours**	**nil**	Farm accounts for taxation; fertiliser supplier	**Simple** Fertiliser supplier	GHG calculator should provide option for inputs of either amount of N or product tonnage per fertiliser type.
Synthetic N fertiliser application method (cropping/ vegetable production only)	**Likely**	**Highly likely**	**<10 hours**	**nil**	Own farm records/contractor records; proof of application/ placement	**Simple** Contractor records; proof of application/ placement	Non-essential for GHG estimates, but needed for capturing incorporation as a GHG mitigation

Table 5: Input information for the revised Detailed method, including sources of information and ease and potential methods for verification/auditing. Note: ratings for ease of supplying suitable data for verification/auditing = simple, challenging.

Input information	Readily available now?	Readily available in the future?	If not, indicative hours for collection	If not, indicative external cost for collection	Potential sources of information	Ease and source for supplying suitable data for verification/ auditing	Notes/comments, including GHG requirements
Area of farm	**Highly likely**	**Highly likely**	**<10 hours**	**nil**	Farm accounts for valuation/taxation	**Simple**	If effective area is required, there may be a cost to the farmer for mapping pasture and crop areas
Monthly/ quarterly animal number split by stock class & age	**Likely**	**Likely**	**<10 hours**	**nil**	All: back-calculate from tax returns, farm management tools. Dairy cattle: Monthly data required for most milk processors; also recorded in MINDA Drystock: Stock sales reconciliation	**Simple** Farm management tools Dairy cattle: Milk processor records, MINDA	Ages: probably unknown for mixed age ewes, cows and hinds; other stock classes OK

Input information	Readily available now?	Readily available in the future?	If not, indicative hours for collection	If not, indicative external cost for collection	Potential sources of information	Ease and source for supplying suitable data for verification/ auditing	Notes/comments, including GHG requirements
Quarterly/key farm operations animal number by body weight	**Unlikely**	**Likely**	**10-50 hours**	**nil**	All: estimate from farm management tools; back-calculate from annual slaughter data but probably under-estimate bodyweight due to culling lighter ewes. For deer, DeerPro useful. Dairy: bodyweight either based on breed or from whole herd weighing 4-5 months after planned start of calving (most farms around for 1 December) (and recorded in DairyBase)	**Challenging** Difficult to verify: Meat company kill sheets; Sale records (incl. estimated bodyweight, not actual bodyweight) but probably under-estimate bodyweight due to culling lighter ewes. For deer, DeerPro useful for estimating. For dairy, based on breed. Farm management tools (e.g. FarmIQ)	Sheep, beef and deer farmers may prefer times of key farming operations (at mating, scanning and weaning). Body weight gain could be estimated within GHG calculator using body weights and dates on/off farm.
Time & animal numbers on off-paddock facilities	**Unlikely**	**Highly likely**	**<10 hours**	**nil**	Farm records; farm management tools	**Simple** Farm records; farm management tools	

Date of start and end of grazing of different feed types	**Likely**	**Highly likely**	**<10 hours**	**nil**	Back-calculate from farm records, Farm management tools	**Simple** Farm records; farm management tools; seed sales (record of purchase	Need to bear in mind that for some crops a transition period will be required. GHG calculator will require a pasture and crop feed quality database (ME, N content).
Imported feed	**Likely**	**Highly likely**	**<10 hours**	**nil**	Farm records; farm management tools Farmers will be required to collect data on supplements. For dairy, this data is required by most milk processing companies.	**Simple** Farm records; farm management tools; supplement purchase records.	GHG calculator will require an imported feed quality database (ME, N content) for purchased supplements and milk powder.
Planned start of mating	**Highly likely**	**Highly likely**	**<10 hours**	**nil**	Farm records; farm management tools	**Simple** Farm records; farm management tools	

Input information	Readily available now?	Readily available in the future?	If not, indicative hours for collection	If not, indicative external cost for collection	Potential sources of information	Ease and source for supplying suitable data for verification/ auditing	Notes/comments, including GHG requirements
Weaning/post-weaning percentages Sheep: Lamb weaning percentage, Dairy: Number of calves post-weaning (retained for R1/beef) Beef: Weaning percentage & stock sales	**Highly likely**	**Highly likely**	**<10 hours**	**nil**	Farm records; farm management tools	**Simple** Tax returns; Farm records; farm management tools	Details of tax returns: Ratio of lambs sold to ewes on hand; Dairy: post-weaned calves sold & replacement rate; Beef: weaning percentage & young stock sales; Deer: weaning percentage. Important to align methods for determining weaning percentages with industry methods (e.g. B+LNZ)
Milk, meat, wool and velvet production per animal type and class	**Highly likely**	**Highly likely**	**<10 hours**	**nil**	Milk processing plants; Meat company kill sheets; DeerPro (for deer); Wool merchants Need to include any on-farm milk used for feeding replacements/retained calves	**Simple** Tax returns Milk processing plants; Meat company kill sheets; DeerPro (for deer); Wool merchants Include any on-farm milk used for feeding	IRD returns may not capture all wool on-hand – can be carried over from one year to the next. In-shed technology (dairy) – provides a check of processors' data. In-shed technology (dairy) provides a check of processors' data. Liveweight gain of young

						replacements/retained calves	stock retained as breeding replacement or finishing stock must be calculated.
Area of farm in different slope classes	**Unlikely**	**Likely**	**<10 hours**	**$10s-$100s**	Farm mapping services, fertiliser companies	**Simple** Farm mapping services, fertiliser companies	One-off requirement; non-essential but enables farmers to capture effect of slope class on N_2O emissions
Effluent/ manure application method	**Likely**	**Highly likely**	**<10 hours**	**nil**	Own farm records/contractor records; proof of application/placement	**Simple** Farm records; Contractor records; proof of application/placement	Non-essential for GHG estimates, but needed for capturing incorporation as a GHG mitigation
Monthly synthetic N applied to soil split into urea, non-urea, urea + urease inhibitor	**Highly likely**	**Highly likely**	**<10 hours**	**nil**	Own farm records/contractor records; proof of application/placement; Fertiliser supplier	**Simple** Fertiliser supplier	
Synthetic N fertiliser application method (cropping/ vegetable production only)	**Likely**	**Highly likely**	**<10 hours**	**nil**	Own farm records/contractor records; proof of application/placement	**Simple** Farm records; Contractor records; proof of application/placement	Non-essential for GHG estimates, but needed for capturing incorporation as a GHG mitigation

4.2 Auditing and verification options

Current sources

Current sources of information for auditing/verification purposes are closely aligned with the information sources farmers will use to determine inputs for a GHG calculation. These include:

- Farm accounts will include stock on-hand at financial year end and sales and purchases are recorded in stock trading records for valuation/taxation. Legal records provide numbers of stock on hand, sales, purchases and losses/deaths. It is important to note that for a significant portion of farms the financial and seasonal year end will be different.

- Milk processing records, meat processor kill sheets, stock sales, weights and dates records (however, not all store lamb/cattle/bull beef sales will have a liveweight associated with them: in these cases, regional + farm class default data from Beef + Lamb NZ economic service data could be used, or certified transport weights used).

- Farm management software (e.g. FarmIQ, Trev, Agrigate, Protrack, MINDA, Macrostock, ProductionWise; meat processor software tools).

- Dairy company annual reporting requirements

- NZFAP+ - NZ National Farm Assurance programme (processed red meat only)

- Fertiliser purchasing records, fertiliser & manure spreading contractor and proof of placement records

Note, farm management software listed above are examples of tools available and those named by the farmers we interviewed; the list is not complete.

For auditing or verification purposes, auditors would be required to work with farmers to access the relevant data. Some of the farm management tools (e.g. FarmIQ) have the ability to capture all of the required inputs for a Detailed GHG calculation. Third party auditing would require permission from individual farmers.

Another option we considered was NAIT (National Animal Identification and Tracing). This system provides information on cattle and deer movement and location, with its use likely to expand to sheep in future years. While it has a built-in auditing system, farmers have found the software very challenging to use and expressed reluctance in using it. More user-friendly software tools, such as LIC's MINDA, can feed data directly into NAIT and is therefore preferred by farmers as a source of data for auditing purposes (and for accessing farm data for conducting a GHG calculation). Access to the data held by NAIT would also require changes to government legislation; if granted, it would provide a suitable potential source of data for auditing purposes. However, improvements to the user interface would increase farmer uptake.

Emerging and future technologies

The largest and most significant opportunity for emerging and future technologies lies with auditing and verifying stock numbers, weights and movements, whereas fertiliser application is relatively well catered for with current options noted above. Emerging and future technologies should be cost-effective while aiming to simplify and improve the accuracy of auditing. Some technologies are increasingly used for auditing/verification purposes, including satellite imagery, geo-tagged photography using smart phones or drones, and precision animal tracking systems.

Satellite imagery is used overseas for auditing purposes. The European Union Common Agricultural Practice (CAP) monitoring programme, using the Sentinel satellite, is capable of monitoring the presence of a catch crop, presence of a N-fixing crop and fallow land (ECA, 2020). However, it is not able to monitor the presence of two species of plants within a catch crop, nor can it detect landscape elements such as rows of trees and hedges that are less than 20 m wide. The review also noted that some agricultural activities such as extensive grazing are difficult to monitor with Sentinel satellites.

Geo-tagged photos using smartphone applications or imagery taken by drones may provide suitable evidence of an activity. Geo-tagged photos can include a time-stamp, which could be used for verifying specific farm activities that are time-sensitive e.g. grazing of specific forages at start and end of a grazing season. New Zealand farmers are already uploading geo-tagged photos to "Cloud farmer", a cloud-based storage service, for farm plans and compliance monitoring (e.g. demonstrating stock are not in rivers). Farmers would then share photos to the appropriate authorities. A review of new technologies to be used in future by European Union agencies monitoring CAP activities (ECA, 2020) suggests the most common technology will be geo-tagged photos, followed by systematic checks using sentinel satellite imagery, while drones were identified as the least common technology to be used. Because geo-tagging is likely to be time-consuming, it would only be done if there was significant benefit to the farmer.

Precision animal tracking systems using GPS or microchip sensors that record animal movements may become a more common on-farm feature. Examples of such systems include:

- Halter
- Low-, or Ultra High- Frequency Radio Frequency Identification (LF-RFID or UHF-RFID)

Halter uses "solar-powered, GPS-enabled smart collars fitted to each cow, allowing farmers to remotely shift, virtually and proactively monitor their cow's health, feed and behaviour" (https://halterhq.com/how-it-works). This information could be overlayed onto a geo-referenced farm map to account for time animals spend on specific forages or time on off-paddock facilities. This system and the associated auditing system would likely be operated by a third party.

An alternative, potentially more cost-effective, option for identifying livestock numbers is radio frequency identification (RFID). Low frequency RFID (LF-RFID) is commonly used for identifying cattle and deer as part of the National Animal Identification and Tracing (NAIT) system, which was introduced to monitor livestock movements due to the risk of TB (which is transmissible to cattle and deer). One of the limitations of LF-RFID is that the tag and the reader need to be very close i.e. ~10 cm distance.

An alternative RFID system is ultra-high frequency RFID (UHF-RFID) which allows greater distances between the tag and reader (up to ~12 m) and can register more tags simultaneously compared to LF-RFID. The UHF RFID protocols are set at an international standard (Global Standard or 'GS1' - see www.GS1nz.org) that allows the transfer of data across the value chain for product verification purposes. In contrast, the current LF-RFID system is only fit for purpose in NZ's animal tracking. All farms have been allocated GS1 identifiers which can be used for farm inputs (such as fertiliser). This technology would allow UHF RFID readers to be deployed at farm gates, providing data on stock numbers and location (at the block/paddock level), which would assist with providing data on the grazing of low GHG forages. This would not be as precise as GPS collars, but they would be more cost-effective. To improve precision, one option would be to include GPS tags on a few animals, to trace the location of a mob within the farm.

A further potential application of the UHF-RFID would be to combine this technology with weigh scales at the gate or scanner to weigh either individual animals or a mob of animals. Investment in integrated farm planning-type approaches may, in future, enable 'block chain'-type security of data collated and used across the supply chain. This type of system, integrated with farm management software (e.g. FarmIQ), would aid data collection and verification of all of the required data for a Detailed farm-scale GHG emission calculation with minimal input from the farmer.

4.3 Further research

This report provides information on farmer inputs required for a revised Intermediate and Detailed method for calculating farm-scale GHG emissions. Through the course of this work, we have identified several areas where further research is required, to ensure farmers are recording the most appropriate inputs. These areas of further research are listed below for He Waka Eke Noa's consideration.

1. Sensitivity analyses should be under-taken for
    a. mature aged stock (e.g. mixed aged ewes) to determine the added accuracy of moving from a constant body weight (i.e. annual body weight) to calculating emissions based on quarterly body weights
    b. drystock to determine the added accuracy of moving from the planned start of mating to the average breeding date, given the potential variation in the spread of lambing
    c. slope classes to determine the added accuracy of moving from slopes determined at the farm scale to the block scale
    d. replacement stock on dairy farms (17-27%) being fed milk powder (representing an additional input of ME and N to the system) to determine the added accuracy by capturing this activity
2. Research will be required to develop a nutrient transfer model (for estimating movement of excreta N from steep slopes to lower slopes) that is fit-for-purpose for farm- or block-scale, in terms of a wide range of ratios in steep:medium:low slope. The current nutrient transfer model (Saggar et al. 1990) was designed for the national agricultural GHG inventory methodology, and not for farm-scale use.
3. Investigate if sufficiently robust temporal N leaching factors for synthetic N fertiliser can be developed, to capture the effects of fertiliser timing on indirect N_2O emissions.
4. Develop default ratios for the proportion of different manure types (liquid, slurry, solid) produced from off-paddock facilities (e.g. wintering pads, standoff pads, feedpads, slatted floor barns, solid floor barns).

5. Acknowledgements

We would like to thank all the farmers interviewed for this report who willingly shared their knowledge and perspectives. We would also like to thank the commercial agritech companies for providing information, as well as comments from Tricia Johnston, David Stevens and Grant Rennie, AgResearch. We also thank our colleagues at DairyNZ, Beef + Lamb NZ, Ministry for Primary Industries, Ministry for the Environment, Foundation for Arable Research and Horticulture NZ for comments made on an earlier version of this report.

6. References

Beukes, P., Romera, A., Hutchinson, K., van der Weerden, T., de Klein, C., Dalley, D., Chapman, D., Glassey, C., Dynes, R., 2019. Benefits and trade-offs of dairy system changes aimed at reducing nitrate leaching. Animals 9.

de Klein, C.A.M., van der Weerden, T.J., Luo, J., Cameron, K.C., Di, H.J., 2020. A review of plant options for mitigating nitrous oxide emissions from pasture-based systems. New Zealand Journal of Agricultural Research 63, 29-43.

ECA, 2020. Using new imaging technologies to monitor the Common Agricultural Policy: steady progress overall, but slower for climate and environment monitoring. Special Report by the European Court of Auditors, Publication Office of the European Union. Pp. 60.

Hutchinson, K.J., Rennie, G.M., Vibart, R.E., Mercer, G.J.K., O'Neill, K., Burtt, A.N., Chrystal, J.M., Devantier, B., Smiley, D.R., Taylor, A.L., Thompson, B.R., Wall, A.J., Dynes, R.A. 2019. Greenhouse gas emissions from New Zealand sheep- and beef farm systems. New Zealand Journal of Animal Science and Production 2019. Vol 79: 56-60.

Luo, J., Balvert, S.F., Wise, B., Welten, B., Ledgard, S.F., de Klein, C.A.M., Lindsey, S., Judge, A. 2018. Using alternative forage species to reduce emissions of the greenhouse gas nitrous oxide from cattle urine deposited onto soil. Science of the Total Environment 610-611: 1271-1280.

Saggar, S., Mackay, A.D., Hedley, M.J., Lambert, M.G., Clark, D.A., 1990. A nutrient-transfer model to explain the fate of phosphorus and sulphur in a Grazed Hill-Country pasture. Agriculture, Ecosystems & Environment 30, 295-315.

van der Weerden, T., Beukes, P., de Klein, C., Hutchinson, K., Farrell, L., Stormink, T., Romera, A., Dalley, D., Monaghan, R., Chapman, D., Macdonald, K., Dynes, R., 2018. The effects of system changes in grazed dairy farmlet trials on greenhouse gas emissions. Animals 8.

van der Weerden T, de Klein C, Dynes R, Selbie D and Vibart 2021. Input specifications for He Waka Eke Noa reporting methods. Report for He Waka Eke Noa (Report Number RE450/2021/024). Pp. 27

van der Weerden, T.J., Noble, A.N., Luo, J., de Klein, C.A.M., Saggar, S., Giltrap, D., Gibbs, J., Rys, G., 2020. Meta-analysis of New Zealand's nitrous oxide emission factors for ruminant excreta supports disaggregation based on excreta form, livestock type and slope class. Science of the Total Environment 732.

Woods, R.R., Cameron, K.C., Edwards, G.R., Di, H.J., Clough, T.J. 2018. Reducing nitrogen leaching losses in grazed dairy systems using an Italian ryegrass-plantain-white clover forage mix. Grass and Forage Science 73: 878-887.

Appendix 1: Differences between revised Intermediate and Detailed methods

There are several key differences between the revised Intermediate and revised Detailed methods. The revised Detailed method captures all the revised Intermediate aspects of a farm GHG footprint, but also captures the following features:

1. on-farm livestock production efficiencies (e.g. higher reproduction efficiencies, higher growth rates)

2. effect of forage type on GHG emissions,

3. effect of storage and land spreading of different types of manure (effluent, slurry, solid manure) on GHG emissions,

4. the potential effect of soil and/or climate on N_2O emissions from urine (this feature is currently unavailable)

5. monthly synthetic N fertiliser use

Differences in calculated farm-scale GHG emissions using the revised Intermediate and revised Detailed methods will most likely be largely due to the former method not being able to account for livestock production efficiencies and the use of low GHG forage types.

Livestock production efficiencies such as higher reproductive efficiencies and higher growth rates ensures relatively more feed is partitioned into product (meat, milk) and less into animal maintenance, thus providing farmers with the opportunity to reduce stock numbers (and therefore GHG emissions) while maintaining production (see van der Weerden et al. 2018; Beukes et al. 2018; Hutchinson et al. 2019).

Differences in forage type can have a significant influence on GHG emissions (see de Klein et al. 2020). For example, grazed plantain (*Plantago lanceolata*) has been shown to reduce N losses from urine patches. Recent research has found that a ryegrass-white clover-plantain sward reduced N leaching by between 45-89% compared to a standard ryegrass/white clover sward (Woods et al. 2018), while a 100% plantain sward reduced N_2O emissions from urine patches by, on average 30% when compared to a standard ryegrass/white clover sward (Luo et al. 2018). These effects will not be captured in the revised Intermediate method because forage type is not included.

Capturing the detailed effects of manure management and monthly synthetic N fertiliser use (as opposed to annual synthetic N fertiliser usage) are likely to have a minor impact on farm-scale GHG emissions, while the impact of soil and climate on N_2O emissions is currently unavailable, and therefore its potential impact on calculated GHG emissions is difficult to assess.

Appendix 2: Stock class/breed options

Livestock type	Class
Sheep	Lambs (incl. Hogget lambs)
	Mature adult ewes
	2t ewes
	Hoggets Ewe
	Hoggets Ram
	Hoggets Other
	Wethers
	Breeding Rams
Beef cattle	Mature adult cows
	Heifers R2
	Heifers R1
	Bull Beef R1
	Bull Beef R2
	Bull Beef R3
	Steers R1
	Steers R2
	Steers R3
	Breeding Bulls
Dairy cattle	Jersey cows
	75% Jersey (J12F4) cows
	KiwiCross (J8F8) cows
	75% Friesian (J4F12) cows
	NZ Friesian cows
	Holstein-Friesian cows
	Heifers R2
	Heifers R1
Deer	Mature adult hinds
	Hinds R2
	Hinds R1
	Stags R1
	Stags R2
	Mature adult stags
	Breeding stags
Goats	Female 1 year +
	Female to 1 year
	Male to 1 year
	Male 1 year +
	Buck

Source: BLNZ benchmarking tool (https://beeflambnz.com/data-tools/benchmarking-tool) & BLNZ GHG calculator (https://yardstick.beeflambnz.com/new).

Appendix 3: Farm management software tools

Software tools available for capturing, reporting and sharing farm information (e.g. Agrigate https://agrigate.co.nz/; Trev https://www.mytrev.com/; FarmIQ https://farmiq.co.nz/; ProductionWise https://productionwise.co.nz and Cloud Farmer https://cloudfarmer.app/) enable farmers to capture and analyse farm data to improve on-farm decision making and performance.

FarmIQ is designed to record a range of farm activities and can be used for feed planning. All animal births, deaths, on-farm movements, transfers and sales records can be captured at individual animal level or mob level. This system can also update NAIT automatically when required. Liveweights and liveweight gains can also be tracked including integration with major weigh scales and electronic tag readers. For auditing purposes, stock information cannot be edited once data is locked. This would occur after approximately 1 year or less, depending on when tally numbers change. Land data is editable for up to 5 years.

Trev and Agrigate capture farm data in a similar manner as FarmIQ to improve on-farm performance. It can record pasture, fertiliser, supplements and stock data, which is then analysed and shared with consultants and farm staff.

ProductionWise is a crop management software tool developed by the Foundation for Arable Research (FAR). Farmers can store crop records, including digital farm mapping and paddock record keeping.

Cloud Farmer allows farmers to record day to day stock sales and purchases, animal health and paddock information including fertiliser use. This tool allows farmers to upload geo-tagged photos, which can be used for auditing and compliance monitoring.

MINDA is a herd management system owned by LIC. This software can link directly with NAIT, making NAIT compliance easy and quick. Farmers can keep track of stock weights, reproduction (pre-mating to mating and calving), and where stock are on farm. However, some farmers will need to improve the accuracy of MINDA records.

Note, these are examples of tools available and discussed by farmers interviewed, the list is not complete.

Appendix 4: Farmer consultation and their comments on calculating GHG emissions

We interviewed 16 farmers and growers to assist with determining input information that is or is not currently collected, including indicative hours, indicative external costs, and potential sources of information. Selection of farmers and growers for interviews was based on contacts provided by agricultural industry representatives within He Waka Eke Noa in addition to several farmers known by the report's authors. Farmers and growers represented dairying, drystock (sheep, beef, deer), mixed cropping and fruit and vegetable production.

Our farmer interviews provided an opportunity to capture thoughts and comments relating to simplifying the GHG reporting process. Below is a summary of comments from individual farmers for developers of GHG calculators to consider.

1. Provide farmers with templates for capturing input information required for GHG reporting.

2. Ensure input templates align with those used for freshwater regulation, milk companies, fertiliser programmes (e.g. Ravensdown's Hawkeye, Ballance's Mitagator). Aim is to avoid duplication of collation of data for different purposes.

3. In-built calculators within the centralised GHG tool for determining time dairy cows are off paddock. Inputs could include how long it takes to milk a herd and number of animals to estimate time off paddocks.

4. Pre-load centralised GHG tool with farmer's values from year before.

5. Current tool used will need to be upgraded to enable reporting required for GHG.