Assessment of tools for estimating on-farm GHG emissions – final report

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agresearch
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Contents

Executive summary

The Ministry for Primary Industries contracted AgResearch to review current options for estimating and reporting on-farm agricultural greenhouse gas (GHG) emissions, in support of future policy decisions. For this project, agricultural GHGs are defined as methane (CH_4) and nitrous oxide (N_2O) emissions from the livestock sector (biological emissions), with arable farming and horticulture being excluded from the analysis.

We assessed six tools/options, ranging from simple calculators to more detailed farm-specific options, against 11 criteria mainly relating to the ‘accuracy and adaptability’, and the ‘feasibility’ of the tools. The purpose of the review was to collate the information, not to provide recommendations on future policy decisions.

The tools/options reviewed included:

1. Estimating emissions per animal or per unit of product
2. Option 1 but with a % reduction in emissions if a mitigation has been adopted
3. Crude energy requirement model (e.g. Lincoln University (LU) Carbon Calculator; http://www.lincoln.ac.nz/research/research/rc/aeru/carbon-calculator/ or Carbon Farming Group (CFG) Calculator https://www.carbonfarming.org.nz/calculators/)
4. Energy requirements and nitrogen (N) model using default values and approaches (e.g. Agricultural Inventory Model (AIM); Gibbs, 2018)
5. Farm-specific model – energy requirements and N model using farm-specific values and approaches (e.g. Overseer; https://www.overseer.org.nz/)
6. Option 5 plus economic/financial impacts of mitigations (Currently no such tool exists, but using Overseer in combination with Farmax http://www.farmax.co.nz/ can provide some of this)

The review was conducted in two parts: i) A stakeholder workshop, and ii) A review of existing reports and information.

The stakeholder workshop was attended by industry and policy representatives, and the participants agreed that the scope of tools/options to be discussed was to include those that *enable i) estimation of on-farm biological GHG emissions for reporting and ii) identification of impacts of mitigation options/farm practices on GHG emissions.* The participants assessed the six tools against 11 criteria using coloured ‘post-it’ notes and commentary (Table 1).

For the review, we used reports recommended by MPI as well as additional reports we were aware of or that were referred to in other reports. We could not find any reports that specifically discussed the pros and cons of simple calculator tools (options 1 and 2). However, some of the reports discussed either the uncertainty associated with estimating GHG emissions per unit of product different pricing and/or mechanisms or ‘points of obligation’ for GHG accountability under the New Zealand Emissions Trading Scheme (NZ-ETS). From these discussions, some of the advantages and disadvantages of the different tools/options could be inferred. We could not find any reports on the ‘crude’ energy requirements model (option 3). There were several reports discussing the relative merits of the more detailed energy requirement approach (option 4) and farm-specific approaches (options 5 and 6), many of these reports directly compared Overseer with AIM.

Key findings

- The simple calculator type tools (options 1 and 2) that estimate emissions per head of animal or per unit of product are easy to use and could be made readily available to end-users (e.g. farmers, land managers, consultants, industry, policy). These tools could deal with changes in stock numbers, although changes in land area may not be well captured. However, these simpler tools are not very accurate in terms of capturing between-farm variability as they use national-average values. They therefore also have limited adaptability when applied at regional, local or farm level scales. In addition, these tools do not consider trade-offs and are not able to support product claims. Furthermore, Journeaux (2019) noted that the more simplistic approach of estimating GHG per unit of product could potentially lead to inequity between stock classes (see section 3.2).
- A key challenge for options 1 and 2 is the ability to verify on-farm animal numbers, which relies on compliance by farmers to provide the numbers as on-farm audits would be complex and costly due to the varied nature of farming. MPI suggested that an alternative approach could be to estimate emissions based on an emissions rate per hectare of pastoral land owned, with emission rates estimated based on intrinsic pasture production potential and assumed animal numbers. Although this approach is possible, the accuracy of the estimates is likely to be low as pasture production is more strongly affected by grazing and cropping management practices (which would not be captured) rather than intrinsic factors. Furthermore, this approach would not account for any emissions associated with the use of imported feeds and supplements.
- Intermediate complexity tools (options 3 and 4) that use generic or national average approaches to estimate animal energy requirements and dry matter intake (DMI) are generally easy to use. Examples of such tools include AIM, the LU Carbon Calculator and the CFG Calculator. Their accuracy, adaptability and ability to account for mitigations or consider trade-offs are limited or non-existent. The LU Carbon Calculator can handle changes in stock numbers and land area, while the CFG Calculator and AIM can only handle changes in stock numbers. The LU Carbon Calculator and the CFG Calculator are accessible on-line, but AIM is currently not publicly available. On the other hand, the AIM methodology is fully transparent and documented and, by default, uses the most up to date the emission factor values. In contrast, documentation on the methodology of the other two tools is lacking and their emission factor values appear to be outdated.
- Farm-specific tools (options 5 and 6) that calculate GHG emissions by using a farm-specific approach for estimating animal energy requirements and DMI, and that consider farm-specific soil and climate conditions are generally accurate, adaptable and able to account for mitigations and consider trade-offs. These tools are also able to deal with changes in stock numbers and land area. However, farm-specific tools are more complex than the simpler tools and verification of all input data will be a key challenge. Farm-specific tools can support product claims, but they are not as easy to use.
- The reports that directly compared Overseer (option 5) and AIM (option 4) showed similar trends in total biological GHG emissions (CH_4 plus N_2O), although Overseer estimates were consistently higher. This is likely to be due to differences in the estimated animal energy requirements and, as a result, dry matter intake (DMI) values. As enteric CH_4 is directly proportional to DMI, this resulted in enteric CH_4 emission estimates from Overseer that were about 25% higher than those estimated using AIM.
- For estimates of N_2O emissions, which are driven by N excreta, Overseer is able to account for differences in N content for different feed types and also allows users to represent more

off-paddock structures and manure management systems (MMS). In contrast, AIM uses a simpler approach based on a single dietary N content and single MMS. Consequently, Overseer is able to capture farm-specific differences compared to the national average approach from AIM. For farm-level estimates of GHG emissions Overseer would, therefore, be considered to be more representative than AIM.

In summary,

- The review has highlighted that there is no 'perfect' tool for estimating on-farm GHG emissions. There are trade-offs to be made between, in particular, *simplicity* and *ease of use* on the one hand, and *accuracy* and *equitability* on the other. The easier a tool is to use, the fewer input parameters are required and the less accurate the estimated GHG emissions are likely to be. This means that capturing between-farm or between-sector variability is more challenging when using more simplistic tools.
- The 'ability to capture between-farm variability' has an important flow-on effect in terms of ability to capture mitigation options, with the latter being a key driver for encouraging on-farm change to achieve reductions in biological GHG emissions.
- The better a tool can capture between-farm variability, the more likely it is it can capture the effects of a wider range of mitigation options. In general,
    - Simple tools can only capture 'output'-based mitigation options, i.e. reducing stock numbers or production.
    - Intermediate complexity tools can capture some management changes (e.g. fewer more efficient animals, changes in N fertiliser use, low GHG animals) or mitigation options (e.g. CH_4 or N inhibitors)
    - Farm-specific tools can capture the management changes and the direct mitigation options listed above for the intermediate tools, as well as more detailed management or mitigation options (e.g. use of low N feeds, enhanced manure management, Once-A-Day milking, land use change/trees on marginal land).
- The management changes and mitigation options that intermediate complexity tools can capture are likely to cover a significant proportion of a farm's biological GHG emissions. However, if further reductions are required to meet New Zealand's reduction targets, farm-specific tools are likely to be needed that can capture the full suite of available management and mitigation options.
- Currently, Overseer is the only farm-specific tool directly available to end-users. As the tool is already widely used for nutrient management it has been recommended by some as the 'tool of choice' for on-farm GHG accounting, while others have raised concerns about its use as a regulatory tool, mainly due to uncertainties and lack of transparency. Following recent reviews, improvements to the GHG modules have been, or are being, made, and further work to refine and document the GHG modules is now being commissioned.

Table 1. Summary assessment by workshop participants of merits of on-farm tools for estimating GHG emissions green=positive; yellow=neutral or intermediate; orange =negative; blue=don't know)

	Criteria:										
Tool:	**1. Goodness of fit**	**2. Captures current and future mitigation options**	**3. Flexibility to include farm energy use and carbon sinks**	**4. Data requirements**	**5. Trade offs/benefits**	**6. Readiness**	**7. Can support product claims**	**8. How big is transition to its use?**	**9. Ease of use/rural professional (RP) support needed?**	**10. Transparency**	**11. Ability to capture changes in stock #s and land area**
1. GHG emissions per unit of product or per animal	Poor accuracy Not fair to all producers Doesn't reward action	Doesn't capture individual action Crude	No Requires another look-up table/tables	Easy to get data Challenge verifying - animal numbers	Cheap, simple; but depends on Point of Obligation (PoO): if processor, good; if farm gate, bad. No ability to ascertain pollution swapping, i.e. exchanging one loss for another	Yes, ready for use	Not ready, not robust enough, not credible	Simple; easy, but for wrong reasons and could lead to wrong decision	Yes	Yes	Stock Yes; land area no
2. Option 1 but with reductions for adopting known mitigations	Poor accuracy; but fairer than option 1	Yes, but at basic level only	No	Mitigation data required	Cheap, simple; but depends on PoO: if processor, good; if farm gate, bad. No ability to ascertain pollution swapping	Relatively quickly to develop, but need mitigation effectiveness data and science	Not ready, not robust enough, not credible without verification, higher cost	Simple; easy, but for wrong reasons and could lead to wrong decision	Yes	Yes	Stock Yes; land area no
3. Crude energy requirement model (e.g. Lincoln C calculator) or combination of lookup table for DMI and fixed CH4	Not fit for nitrous, but OK for CH4; good alignment with national inventory	No; Doesn't capture change over time (consistency)	No is static, but gives more complete picture (including energy, forestry etc)	Relatively easy to obtain	Very limited	Ready for use by farmers	Not sure. Pretty flimsy support of DMI to CH4; number claims.	transition easy - animals numbers in + x out	In use now	Should be/could be ? Maybe	Stock numbers - depends on boundaries and time scales (stock on/off) time in/out. Can't capture changes in land area
	Summary of Option 3 from one group: More detailed compared with options 1 and 2. But worry about having the worst features of both look-up table and models										
4. Energy requirements and nitrogen model using default values and approaches (e.g. AIM)	Farm type specific - not geospatial (weather, soils); nearly green	OK for CH4; missed N2O; management changes; captures simple mitigations	Not spatial so hard to include riparian and poplar plantings	More data needed- some will be harder than others, eg, dairy vs remote. Currently not possible to verify monthly stock numbers on the vast majority of farms.	No trade offs, no pollution swapping - some co-benefits; But is recognised tool	Not ready for use. Needs user interface	Is a recognised tool but verification of outputs is needed	Big - no-one currently (except MPI & AGR) and not known	bit unknown - conceptually could be easy	Transparent - engine findable	Stock/numbers Yes Land area no
5. Farm-specific model – energy requirements and nitrogen model using farm-specific values and approaches	Less uncertain than others. Estimates what is there, which is good for equitability (depending on how its used); More detail avoids over-estimating emission for some farmers	Yes we hope so; the more flexibility the better	Spatial data may help capturing on-farm vegetation	Does need more data but should be available; may be challenging for some data eg, riparian or GPS for fertiliser appln. Currently not possible to verify monthly stock numbers on the vast majority of farms.	Already used; Can do N leaching and fert recs; Richer understanding of farm systems - better advice However, trade-off is time, cost, verification	One tool is available that is available (Overseer); no other tool known	Able to support some claims (for farm) and feeds into wider footprint certification	Still significant portion of farmers not engaged in such a tool; New to Overseer wouldn't be able to use FM without help	Overseer: better and getting better; May need consultants especially for mitigations; Not all consultants good on all farm systems	Overseer transparent models published; but generally complex models are hard to understand even if open; can be transparent via 'expert' review	Yes
	Summary of Option 5 from one group : good to have not a priority for now										
6. Option 5 plus economic/financial impacts of mitigations	Yes	Allows scenario analogy - easy to adopt	Yes	more financial data makes harder. Could be yellow Depends on the level of detail	Builds on existing analysis. Can use with bank	Needs development Even FARMAX not ready	Unsure/unclear	Unsure/unclear	Unsure, but this is not easy and definitely RP input for the vast majority of farms.	As a tag-on to 5	As a tag-on to 5

1. Introduction

The Ministry for Primary Industries has contracted AgResearch to lead a project on the assessment of current tools available to estimate and report agricultural greenhouse gas (GHG) emissions at farm-scale.

For this project, agricultural GHG are defined as methane (CH_4) and nitrous oxide (N_2O) emissions from the livestock sector (biological emissions), with arable farming and horticulture being excluded from the scope of this analysis.

The project outcomes are intended to support future policy decisions on agricultural CH_4 and N_2O emissions by extending previous analyses that were undertaken and reported in a range of reports. In this project we assessed a range of available tools and options for estimating GHG emissions against their i) accuracy and adaptability (e.g. flexibility to account for, or incorporate, mitigation options and goodness of fit); and ii) their feasibility (e.g. data input requirements, access and verifiability). The purpose of the review was to collate the information, not to provide recommendations on future policy decisions.

2. Approach

The project includes two main components: 1) a stakeholder workshop and 2) a review of existing reports and information.

2.1 Stakeholder workshop

A workshop entitled ‘tools for estimating and reporting GHG emissions’ was held on 2 May 2019, in Wellington.

The workshop was attended by representatives from industry and policy: Beef+Lamb NZ, DairyNZ, DeerNZ, Federated Farmers, Fertiliser Association NZ, Fonterra, Ministry for the Environment, Ministry for Primary Industries, Overseer Ltd and AgResearch.

The purpose of the workshop was to i) identify existing and potential tools/options for agricultural methane and nitrous oxide emissions estimation and reporting; and ii) to identify trade-offs and co-benefits of these options.

The workshop focused on technical and practical implementation issues associated with these tools/options rather than broader policy or political considerations (such as whether regulations or a price-based mechanism are the most effective way to address emissions).

Please refer to Appendix 7.1 for further details on the attendees, agenda and outputs of the workshop.

The participants of the stakeholder workshop, agreed to the following scope for the tools and options discussed at the workshop:

Enable i) estimation of on-farm biological GHG emissions for reporting and ii) identification of impacts of mitigation options/farm practice on GHG emissions.

2.1.1 Tools and options to be assessed

Possible options for tools/options for estimating on-farm GHG emissions were identified and discussed with workshop participants, and the following options were prioritised for further assessment, ranging from simple calculators to more complex farm-specific options:

Simple tools/options:

1. GHG emissions per unit of product or per animal
2. Option 1 but with reductions for adopting known mitigations

Intermediate complexity tools/options:

3. Crude energy requirement model (e.g. Lincoln University (LU) Carbon Calculator http://www.lincoln.ac.nz/Research/Research/RC/AERU/Carbon-Calculator/)
4. Energy requirements and nitrogen (N) model using default values and approaches (e.g. Agricultural Inventory Model, AIM; Gibbs, 2018)

Farm-specific tools/options:

5. Farm-specific model – energy requirements and N model using farm-specific values and approaches (e.g. Overseer; https://www.overseer.org.nz/)
6. Option 5 plus economic/financial impacts of mitigations

All options are based on the generic principles of estimating energy requirements and associated dry matter intake (DMI) of the animals, based on animal population and production characteristics. However, options 1, 2 and 3 use average GHG emissions factors (per animal and/or per product) that are generally inferred from the national inventory calculations. In contrast, options 4, 5 and 6 estimate energy requirements and dry matter intake, and use CH_4 yield (g CH_4/kg DMI) and N content of the diet to determine enteric CH_4 emissions, N intake and excretion and associated N_2O emissions. The different options evaluated use different levels of detail for estimating energy requirements and dry matter intake. AIM uses national averages for animal population and production (Figure 1), while Overseer uses farm-specific information for these inputs. In addition, Overseer can capture differences in animal diet characteristics, while AIM assumes all animals consume the same diet with a fixed digestibility, and energy and N contents (Figure 2).

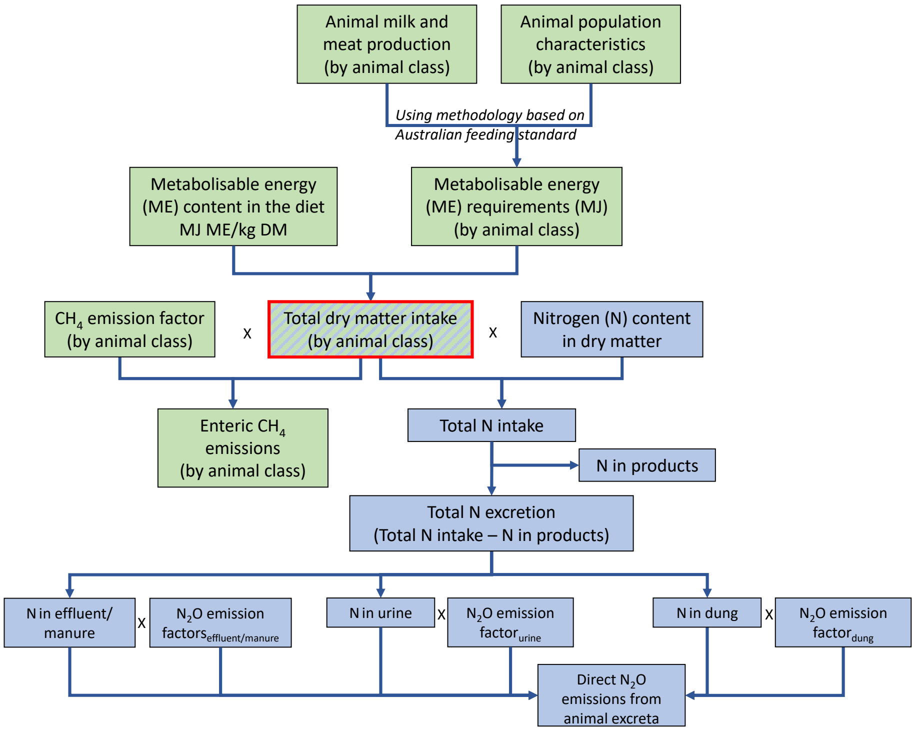

Figure 1: Schematic overview of the basic approach in AIM for estimating methane (CH_4) and nitrous oxide (N_2O) emission for animal production systems. Green boxes refer to CH_4, blue boxes to N_2O. MJ = Mega Joules (after de Klein et al. 2017).

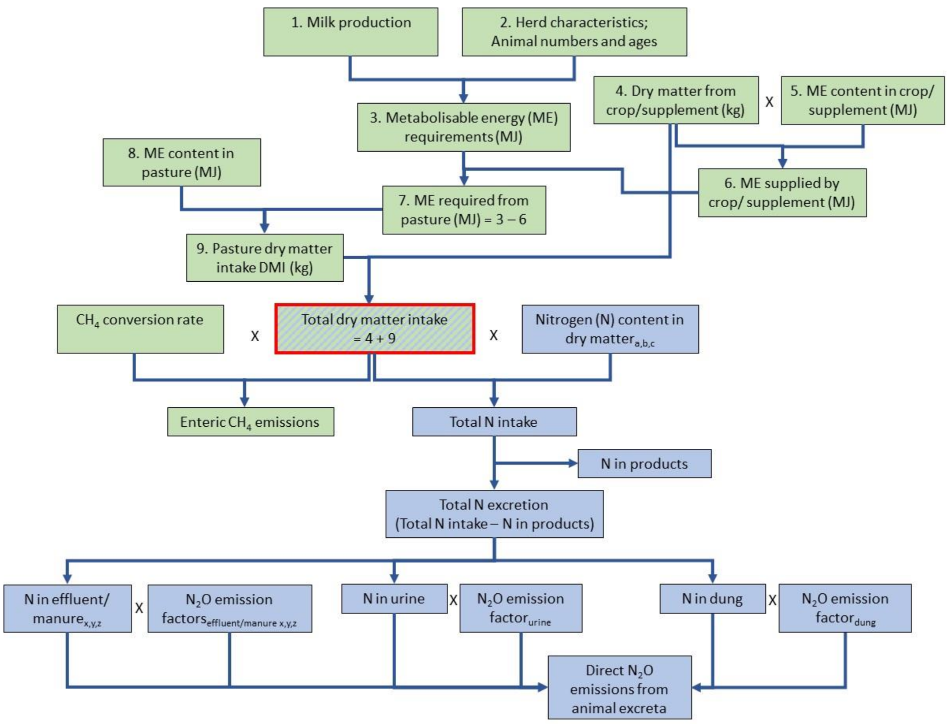

Figure 2: Schematic overview of the basic approach in Overseer for estimating methane (CH_4) and nitrous oxide (N_2O) emission for animal production systems. Green boxes refer to CH_4, blue boxes to N_2O. DMI = dry matter intake; ME = metabolisable energy; MJ = Mega Joules; dry $matter_{a,b,c}$ = dry matter of feed types a, b or c; $manure_{x,y,z}$ = manure management system x, y or z. (after de Klein et al. 2018).

2.1.2 Assessment criteria

An initial list of criteria for assessing the tools/options was provided by MPI. This list was discussed and expanded on during the workshop. The final set of criteria that were agreed were:

1. Goodness of fit/uncertainty of estimates; are they fair and equitable between different farming types and sectors?
2. Can effects of current and future mitigation options, and advances in science, be captured?
3. Is the tool/option flexible enough to include farm energy use, soil C and forest sinks?
4. What are the input data requirements? How available are the data? Are inputs independently verifiable?
5. What are the potential trade-offs/co-benefits (e.g. already in use for something else; cost)?
6. What is the 'readiness' of the tool/option? Is it available now or does it need to be (further) developed?
7. Does it have the ability to support product claims (e.g. does it include a full life-cycle assessment)?
8. How great is the transition towards using this tool?
9. How easy is it to use? Is support from advisors or rural professionals needed?
10. How transparent are the workings of the tool?
11. Can the tool deal with changes in stock numbers and land area (e.g. movement of stock between farms)?

2.2 Review of existing reports and information

Following the workshop, we reviewed existing reports and information and collated information relating to the tools/options and assessment criteria agreed in the workshop.

MPI requested that the following reports were included in the review:

1. Assessment of the administration costs and barriers of scenarios to mitigate biological emissions from agriculture (BECCA, 2018)
2. Overseer and regulatory oversight: Models, uncertainty and cleaning up our waterways (PCE, 2018)
3. Initial review of the suitability of OVERSEER Nutrient Budgets Model for farm scale greenhouse gas reporting (de Klein et al. 2017)
4. Fonterra GHG benchmarking – Agricultural Inventory Model (MPI) and OVERSEER (Rollo et al. 2018)
5. Productivity Commission, Low-emissions economy (NZPC, 2018)
6. Reporting agricultural emissions at farm level (KPMG, 2012)

7. Desk-top review of GHG components of OVERSEER (Kelliher et al. 2015)

In addition, we also included the following reports in the review:

8. On-farm options to reduce agricultural GHG emissions in New Zealand (Reisinger et al. 2017)
9. Future options to reduce biological GHG emissions on-farm: critical assumptions and national-scale impact (Reisinger et al. 2018)
10. Report of the Biological Emissions Reference Group (BERG, 2018)
11. Alignment of OVERSEER® with GHG policy mechanisms (de Klein & Kelliher, 2018)
12. Mitigating agricultural GHG emissions Strategies for meeting NZs goals (Gluckman, 2018)
13. Assessing the Nationwide Economic Impacts of Farm-level Biological GHG mitigation options (Djanibekov et al. 2018)
14. Review of agricultural greenhouse gas emission factors (Journeaux, 2019)
15. Managing GHG emissions on dairy farms – Knowledge and tools to build a professional greenhouse gas workforce (de Klein et al. 2016)

3. Results

3.1 Stakeholder workshop

Workshop participants worked in three break-out groups to develop a 'matrix' that provided a colour assessment of each criteria against each tool using coloured 'post-it' notes (green for positive impact, yellow for neutral, and orange for negative impact). Participants were also asked to provide a narrative for each assessment. When the groups had completed their assessment the flipcharts with the 'post-it' notes were posted on the wall and the results compared and discussed in a plenary session (see Appendix 7.1 for photos of the actual flipcharts).

Following the workshop, the results were collated into one table (see Appendix 7.2) and the assessments were compared and summarised. The key findings were that:

- The assessments by the different groups generally aligned well
- The simpler tools (e.g. options 1 and 2) predominantly scored:
  - orange for 'accuracy and adaptability', 'trade-offs' and 'ability to support product claims' (criteria 1-3, 5 and 7)
  - green for 'feasibility' (criteria 4, 6, 8-10)
  - green for 'ability to deal with changes in stock numbers' (criteria 11), but with some caution regarding not being able to capture changes in land area
- The intermediate complexity tools (e.g. options 3 and 4)
  - generally scored orange or yellow for 'accuracy and adaptability' and 'trade-offs'
  - had a varied response (but not orange) to 'can support product claims'

- generally scored green for 'feasibility' for option 3, but a more varied response (including some orange) for 'feasibility' for option 4
- had a varied response for 'ability to deal with changes in stock number and land area' with again some caution re not able to capture changes in land area

- The farm-specific tools (e.g. options 5 and 6)

generally scored green for 'accuracy and adaptability' and 'trade-offs'

- had a varied response (but not orange) to 'can support product claims'
- had a varied response (including some orange) for 'feasibility'
- scored green for 'ability to deal with changes in stock number and land area'

Key points that were raised by workshop participants during the discussion:

- Farmers should be able to capture all this information available, but historically this has not been done.
- Should "exception" reporting be considered (i.e. GHG reporting is only required when actual performance deviates significantly from the average or expectations)?
- Farmers will make decisions based on economics but will need some assessment of cost/benefits
- There are diminishing returns regarding mitigating N_2O emissions as it represents only *ca* 20% of total emissions
- Verifiability of animal numbers and many input data is challenging; automated reporting can help
- Is there an opportunity to use the National Animal Identification and Tracing (NAIT) system?
    - There is good compliance for animals to slaughter but not for between-farm movement of animals (the government is changing the NAIT Act to improve compliance)
    - NAIT could be used to collect data for different purposes, but it is difficult to get hold of the data.

3.2 Review of existing reports and information

Relevant content of the various reports was collated for the six tools and 11 assessment criteria (see Appendix 7.3 for details). The summary findings are:

Options 1 (GHG per product or animal) and 2 (with reductions for mitigations)

Existing reports were reviewed, and information was collated on the tools/options and criteria agreed at the stakeholder workshop. There was limited relevant information in the reports on the first two tools/options (GHG emissions per unit of product or per animal; and this option with reductions for adopting known mitigations). However, Journeaux (2019) estimated emission factors per product using the national inventory model and concluded these needed to be updated on an annual (or rolling average) basis to account for changes to the inventory methodology. If emission factors are calculated based on an assumed static national herd-size, there will be a 'lag effect' in the calculated values if the size of the national herd is either increasing or decreasing (Journeaux 2019). This issue could be minimised by using a rolling average to smooth the changes in the emission factors.

The methodology proposed by Journeaux (2019) for calculating emission factors for each of the different stock types resulted in significant differences between them, and the "…(reason for) the disparity between the stock types is not that obvious". "Until this apparent anomaly between the stock types is resolved, the recommendation is to use the 'cattle' emission factors for all main livestock classes (Journeaux 2019). Furthermore, this approach does not capture differences in feed conversion efficiency between individual animals.

The 'Low-Emissions Economy' report from the Productivity Commission (NZPC 2018) did not discuss tools for estimating GHG emissions per se but reported on the merits of setting the point of obligation (PO) for agriculture at the processor level or at the individual farm level. However, from this PO assessment, implications for tools and options for estimating emissions could be inferred. For a processor PO, options 1 or 2 would suffice as the estimates of emissions would be based on national averages (e.g., average emissions per head of animal or average N_2O emissions for a tonne of N fertiliser used). As already mentioned during the stakeholder workshop, NZPA (2018) also suggested that although this option may be easier to adopt, it would provide little direct incentive for farmers to change management practices.

No reports specifically discussed option 2 in the context of the assessment criteria. However, it is referred to in a few reports (e.g. de Klein and Kelliher, 2018 and NZPC, 2018) as an option that has the simplicity of option 1, yet provides some incentives for adopting mitigation strategies. Rebates can be given based on national average assessments of the effect of the mitigation options, or a farm-specific model could be used to assess farm-specific effectiveness of the mitigation options. The latter could help inform the level of rebate for each GHG reduction practice and the on-farm value of implementing the GHG reduction practices (de Klein and Kelliher, 2018).

A key challenge for options 1 and 2 is the ability to verify on-farm animal numbers, which relies on compliance by farmers as the dispersed nature of farming makes any audits very difficult. This would also be very costly as it would require the regulator to assess the on-farm emissions for each farmer. This would be challenging (if not impossible) where a farmer refuses to supply detailed farm level information or where farmers have poor record keeping. As discussed in the stakeholder workshop, there is a possibility in the future to use NAIT for verifying on-farm animal numbers, once NAIT compliance increases.

MPI also suggested an alternative approach to deal with the challenges of verifying farm records and reporting that allows the regulator to calculate on-farm emissions by proxy/remotely. This alternative option could be to estimate on-farm emissions by applying an emissions rate to every hectare of pastoral land owned each farmer. The area of pastoral land would be based on the latest Land Cover Data Base (LCDB). The emissions rate(s) would be from a national emissions map which would be derived from a national map of intrinsic grass growth potential and assumed stocking rates. The national map of intrinsic pasture production would be derived using characteristics such as soil types, slope, climate, rainfall and aspect. As grass growth is linked to farm management practice, typically farm management practices would be assumed. Although this option is possible, it is uncertain whether the level of accuracy would be better than with a system that relies on on-farm recording and reporting of animal numbers. Pasture production is likely to be more strongly affected by management factors (e.g. grazing management, cropping or the use of imported feeds or supplements) than by intrinsic factors, and as management practices would not be captured this creates uncertainty about the actual compared with the potential pasture production.

The ability to provide sufficient verifiable information is not unique for GHG accounting but is also required for, for example, developing farm environment plans. It would therefore be advisable to align with or utilise existing approaches or systems that capture and report on-farm information, rather than develop a GHG accounting mechanisms in isolation.

Option 3 (Crude energy requirement model)

There was no mention of the LU Carbon Calculator in any of the reports reviewed. However, we checked the model on-line. This model requires basic farm-level information (e.g. animal numbers, production, fertiliser use etc) but it is not clear how the model uses this input information to estimate the GHG emissions. The description states it uses the inventory emission factors from the 2016 National GHG Inventory, but does not give the actual values, so it is not possible to check what values are used. An on-line search also revealed a second calculator from the Carbon Farming Group[1], which is intended to assess "….liabilities using data averaged across New Zealand conditions." The calculator requires simple inputs of animal stock numbers, production levels and fertiliser use, and uses the agriculture emission factors from the "..Climate Change (Agriculture Sector) Regulations 2010." As for the LU calculators, the actual emission factor values are not given so it is not possible to check these. However, if they are indeed from 2010, these emission factor values are outdated by almost a decade.

Options 4 and 5 (Energy requirements and N model using national average or farm specific values and approaches)

The fourth and fifth types of tool were mentioned in many of the reports. More specifically, the reports referenced the national Agricultural Inventory Model (AIM; option 4) and Overseer (option 5), respectively. As can be seen in report titles, many compare, or focus exclusively, on Overseer. All reports used Overseer 6.3.0 or an earlier version.

To the best of our knowledge, and as often mentioned in the reports and publications, Overseer is the only farm-specific tool in New Zealand for estimating GHG emissions. The tool is already widely used in some sectors and, as a result, has been recommended as the 'tool of choice' for on-farm GHG accounting by a cross-sector Stakeholder Advisory Group (SAG) that was set up as part of a DairyNZ PGP project on 'knowledge and tools for building a GHG capable workforce' (de Klein et al. 2016). More recently, the use of Overseer as a regulatory tool has been discussed (e.g. Gluckman 2018; PCE 2018). Gluckman (2018) concluded that the suitability of Overseer as a direct regulatory tool for estimating on-farm GHG emissions was limited due to the range of uncertainties associated with the tool. The PCE report (PCE 2018) focused on Overseer as a tool to manage diffuse nutrient pollution, but its recommendations on the need for "…transparency, peer review, corroboration, uncertainty and sensitivity analysis, and model documentation…" certainly apply to any regulatory use of Overseer as a GHG accounting tool. In recent years, several reviews have been conducted on the underlying science and the suitability of Overseer for estimating farm-scale GHG emissions (e.g. Kelliher et al. 2015; Pacheco et al 2016; de Klein et al. 2017; de Klein et al. 2019). Recommendations from these studies on improvements to the energy and N_2O modules

[1] https://www.carbonfarming.org.nz/calculators/

of Overseer have been, or are being, implemented. In addition, further work on the refinement and documentation of the GHG modules is currently being commissioned (C. Read pers. com.).

NZPC (2018) discussed the feasibility and practicability of estimating GHG emissions at the farm level and commented that, while it's intended use initially was a fertiliser and nutrient management tool, Overseer has been developed over time and can now also estimate on-farm GHG emissions. It does this by combining farm-specific input data, and estimated energy requirements and dry mater intake, with emission factors from AIM. However, further work is needed to improve its transparency, the extent to which it captures a wide range of on-farm mitigation options, and to better align the model to the methodology used in preparing the national inventory (NZPC 2018; PCE 2018).

Several reports compare the farm-specific approach of Overseer with the national inventory approach of AIM (e.g. Kelliher et al. 2015; Rollo et al. 2018). Rollo et al. (2018) compared outputs from Overseer and AIM by running *ca* 100 Overseer files and extracting relevant information from each file to run AIM: monthly animal numbers for dairy classes, milk yield/cow, total fertiliser N applied. As AIM is a national average model, some approximations and adjustments to AIM were required to allow AIM to run using the farm-level information extracted from Overseer files. The key findings of this comparison were that Overseer and AIM showed similar trends in total GHG emissions (CH_4 and N_2O), but the Overseer estimates were consistently higher. This is likely to be due to differences in the estimated animal energy requirements and, as a result, dry matter intake (DMI) values. As enteric CH_4 is directly proportional to DMI, this resulted in enteric CH_4 emissions estimates in Overseer that were about 25% higher than those made using AIM. In addition, DMI is also a key driver of N_2O emissions estimates as it determines N intake and thus N excretion values. However, the comparison of N_2O emission estimates between Overseer and AIM was more variable than for CH_4 emissions (R^2=0.986 for CH_4 and R^2=0.852 for N_2O). Key reasons for this are that Overseer can account for differences in N content for different feed types and also allows users to represent more off-paddock structures and manure management systems (MMS). This results in a large number of pathways for excreted N (NEx) to be managed, with direct N_2O emissions occurring along the manure management pathway. In contrast, AIM uses a fixed proportion of NEx going into one generic MMS with fixed N_2O emission factors. This reflects the ability of Overseer to capture farm-specific differences compared to the national average approach from AIM.

Reisinger et al. (2018) evaluated current and future options for reducing biological GHG emissions. They provided both a qualitative assessment of the availability of each option and barriers to their adoption, as well as a quantitative assessment of GHG reduction estimates that could be achieved annually. For the latter, they used, where possible, AIM, supplemented with additional modelling or spreadsheet modelling, where needed. One of their criteria for the qualitative assessment on the risks to adoption was 'ease of monitoring and accounting'. They suggested that the mitigation options that could be readily and currently accounted for using AIM were CH_4 vaccine, CH_4 or N inhibitors, low GHG animals, reduced N fertiliser use, and fewer more efficient animals. The mitigation options that required more detailed farm-specific modelling or information included low GHG feeds, enhanced manure management, once-a-day milking, and land-use changes/ planting trees on marginal land.

Overseer also appears to be the only tool that captures farm energy use and embedded carbon in bought-in fertiliser and feeds. Discussions are underway about including forestry sinks. Changes in soil carbon are very difficult to measure and tools that can assess these changes stocks are probably some way off from being developed.

Options 6 (farm-specific tool with economic/financial impacts of mitigations)

There is an obvious advantage in having a tool that can provide both a GHG estimate as well as an assessment of the financial implications of GHG mitigations. We could not find any reports on one tool that can do both. However, Reisinger et al. (2017) combined Overseer with Farmax modelling to derive GHG emission estimates and costs of mitigations. Farmax is a farm system and economic simulation model that calculates the required feed demand for a modelled livestock system within the constraints of user-defined pasture growth rates and animal performance data. It allows users to evaluate the economics of alternative livestock policies. Farmax does not provide estimates of GHG emissions, but these are derived from Overseer. However, using the two models in combination requires the information to be manually transferred between the models and any change in one model requires a change in the other.

4. Conclusions

Key findings

- The simple calculator type approaches (options 1 and 2) are easy to use. Although currently not readily available, they would be relatively easy to develop, especially if national average GHG values per animal or per unit of product would be published (and regularly updated) on a website. Such tools are able to deal with changes in stock numbers, although changes in land area may not be well captured. However, these simpler tools are not very accurate as they use national-average values and have limited adaptability. In addition, these approaches can only capture 'output'-based mitigation options (i.e. reducing stock numbers or production) and not changes in management or specific mitigation options (e.g. CH_4 or N inhibitors). They also do not consider trade-offs and are not able to support product claims. Furthermore, Journeaux (2019) noted that estimating GHG per unit of product could lead to uncertainty and potential inequity between stock classes.
- A key challenge for options 1 and 2 is the ability to verify on-farm animal numbers, which relies on compliance by farmers to provide the numbers as on-farm audits would be complex and costly due the dispersed nature of farming. MPI suggested an alternative approach could be to estimate emissions based on an emissions rate per hectare of pastoral land owned, with emission rates estimated based on intrinsic pasture production potential and assumed animal numbers. Although this approach is possible, the accuracy of the estimates is likely to be low as pasture production is more strongly affected by management practices (which would not be captured) rather than intrinsic factors.
- Intermediate complexity tools (options 3 and 4) that use generic or national average approaches to estimate animal energy requirements and dry matter intake (DMI) are generally easy to use and these tools can provide a quick (albeit generic) assessment of a farm's GHG emissions. However, their accuracy, adaptability and ability to account for mitigations or consider trade-offs, are limited or non-existent.

- Examples of intermediate complexity tools include AIM, the LU Carbon calculator and the CFG calculator. Of these, AIM is currently not publicly available, but the latter two are accessible on-line. However, clear documentation on the methodology of these two tools is lacking, while the AIM methodology is fully transparent and well-documented. Furthermore, AIM uses, by default, the most recent emission factor values, whereas it is unclear how up-to-date the emission factors are that are used in the LU and CFG calculators as they are using 2016 and 2010 AIM values, respectively. The LU Carbon Calculator can handle changes in stock numbers and land area, while the CFG Calculator and AIM can only handle changes in stock numbers. Stock numbers and land area are users' inputs to the LU Carbon Calculator, so this tool could easily handle changes in stock number and land area. The CFG calculator and AIM can handle changes in stock numbers, but not land area.
- Farm-specific tools (options 5 and 6) are considered to be generally accurate, adaptable and able to consider trade-offs. These tools also are able to deal with changes in stock numbers and land area, and could support product claims. However, they are less easy to use as more simplistic tools. A point that was not raised in the discussions but is important to note is that, due to the increased complexity of the farm-specific tools, verification of all input data required to run the farm-specific tools will be a key challenge.
- The reports that directly compared Overseer and AIM showed similar trends in total GHG emissions (CH_4 and N_2O), although Overseer estimates were consistently higher by about 25%. This is likely to be due to differences in the estimated animal energy requirements and, as a result, dry matter intake (DMI) values.
- For estimates of N_2O emissions, which are driven by N excreta, Overseer is able to account for differences in N content for different feed types and also allows users to represent more off-paddock structures and manure management systems (MMS). In contrast, AIM uses a simpler approach based on a single dietary N content and single MMS. Consequently, Overseer is able to capture farm-specific differences compared to the national average approach from AIM. For farm-level estimates of GHG emissions Overseer would, therefore considered to be more accurate than AIM.
- Overseer is the only currently available farm-specific tool in New Zealand for estimating GHG emissions. The tool is already widely used in some sectors and, as a result, has been recommended by some as the 'tool of choice' for on-farm GHG accounting. However, there are also concerns about the use of Overseer as a regulatory tool due to the uncertainties associated with the GHG estimates and the lack of transparency and documentation of the GHG modules and the emission factors that are used. In recent years, several studies have reviewed the GHG modules of Overseer and recommendations on improvements have been, or are being, implemented. In addition, further work to refine and document the N_2O module is currently being commissioned.

In summary,

The review has highlighted that there is no 'perfect' tool for estimating on-farm GHG emissions. There are many trade-offs between the different criteria. The authors suggest that in particular, *simplicity* and *ease of use* on the one hand, and *accuracy* and *equitability* on the other, are the key conflicting areas. The easier a tool is to use, the fewer input parameters are required and the less accurate the estimated GHG emissions are likely to be. This means that capturing between-farm or between-sector variability is more challenging when using more simplistic tools. This has important flow-on effects for a tool's ability to capture mitigation options, which is a key driver for encouraging the on-farm change that will ultimately be needed to achieve the required reductions in biological GHG emissions. In general, the better a tool can capture between-farm variability, the more likely it is it can capture the effects of a wider range of mitigation options.

Simple tools can only capture 'output'-based mitigation options, i.e. reducing stock numbers or production. Intermediate complexity tools can capture some management changes (e.g. fewer more efficient animals, changes in N fertiliser use, and low GHG animals) or mitigation options (e.g. CH_4 or N inhibitors). Although, these management changes and mitigation options are likely to cover a significant proportion of a farm's biological GHG emissions, further reductions may be required to meet New Zealand's reduction targets. To achieve and encourage these reductions at the farm-level, farm-specific tools are needed that can capture the management changes and the direct mitigation options listed above for the intermediate tools, as well as more detailed management of mitigation options (e.g. use of low N feeds, enhanced manure management, Once-A-Day milking, and land use change/trees on marginal land). Currently, Overseer is the only New Zealand farm-specific tool directly available to end-users. Although opinions are divided on its suitability as an on-farm GHG accounting tool, mainly due to uncertainties and lack of transparency, work is underway to update and refine the GHG modules and to improve the model documentation and transparency.

5. Acknowledgements

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7. Appendices

7.1 Stakeholder workshop

A workshop entitled ‘tools for estimating and reporting GHG emissions’ was held on 2 May 2019, at the Terrace Conference Centre, 114 The Terrace, in Wellington

The workshop attendees included:

Victoria Lamb (*Beef+Lamb NZ*); Matthew Newman (*DairyNZ*); Lindsay Fung (*DeerNZ*); Macaulay Jones (*Federated Farmers*); Greg Sneath (*Fertiliser Association NZ*); Ross Abercrombie and Andrew Kempson (*Fonterra*); Andrea Brandon (*Ministry for the Environment*) Chris Kerr, Gerald Rys, Kristen Green, Darran Austin, Joel Gibbs, Hazelle Tomlin and Run Qing Tong (*Ministry for Primary Industries*); Caroline Read and Kayo Sakey (*Overseer Ltd*); Cecile de Klein and Mike Rollo (*AgResearch Ltd*).

Other invitees but unable to make the workshop:

Kimberly Crewther (*Dairy Companies Association NZ*); Milena Scott (*DairyNZ*); Lucas Kengmana (*Fonterra*); Michelle Sands (*Horticulture NZ*); Kelly Forster (*ICCC*); Paul Goldstone (*Meat Industry Association*); Laura Symes (*MfE*); Tess Dixon, Christopher Holland and Toni Wi (*MPI*); Tony van der Weerden (*AgResearch Ltd*).

Workshop Purpose

The purpose of the workshop was to i) identify existing and potential tools/options for agricultural methane and nitrous oxide emissions estimation and reporting; and ii) to identify trade-offs and co-benefits of these options.

Workshop Outputs

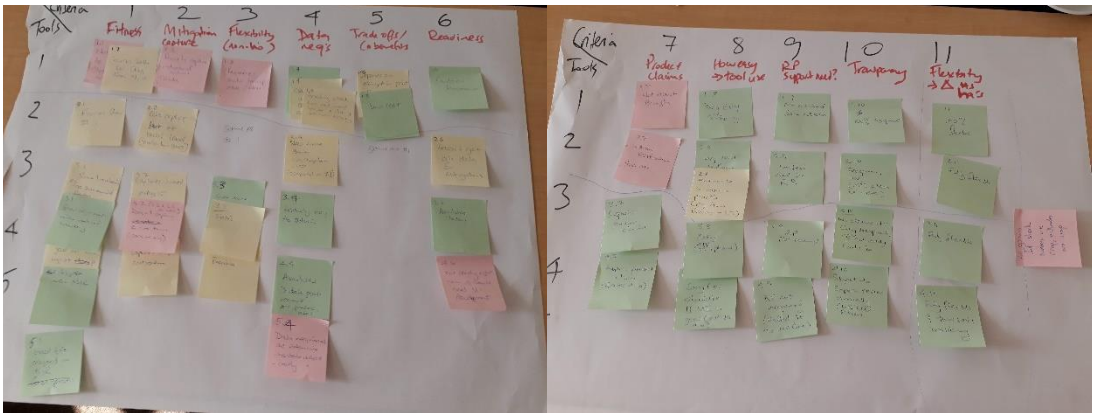
1. Overview of current and potential options
2. Assessment of each option against a range of criteria (e.g. accuracy, capturing mitigation, adaptability, complexity, verifiability). Agreed traffic light overview with underpinning narrative.

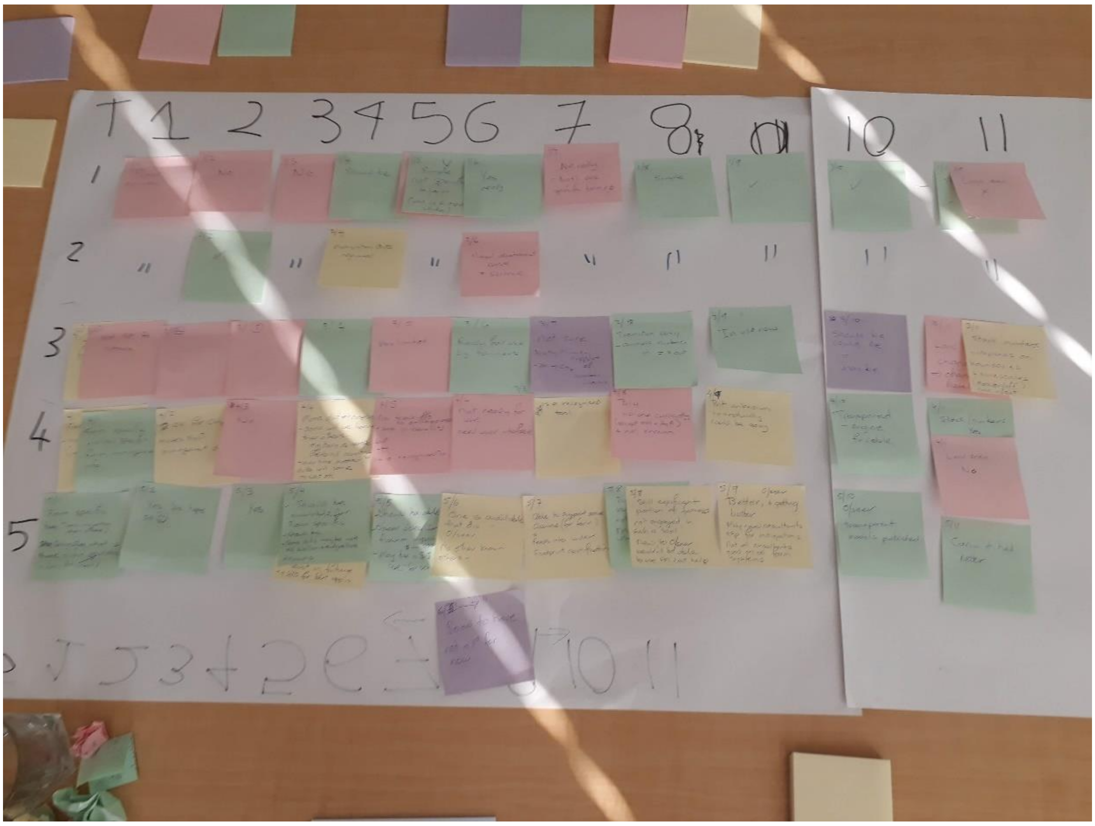
The workshop focused on technical and practical implementation issues associated with these tools/options rather than broader policy or political considerations (such as whether regulations or a price-based mechanism are the most effective way to address emissions).

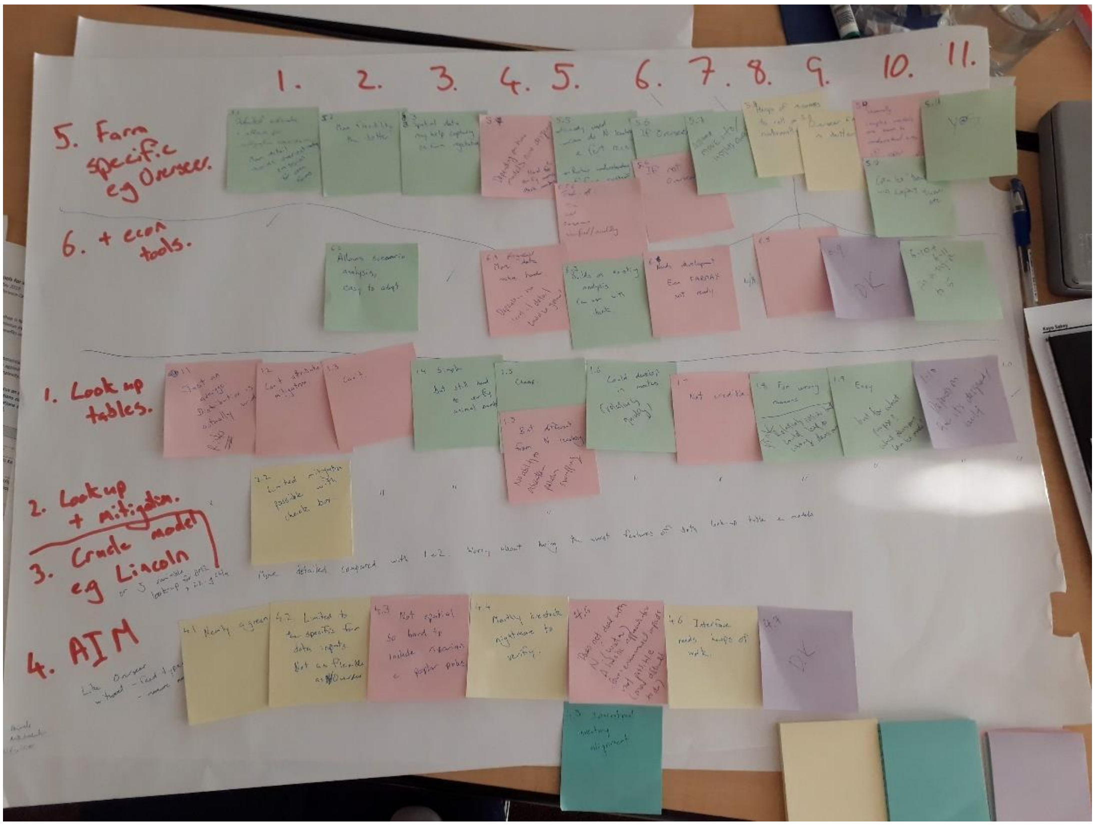
Workshop Agenda

Time	Purpose
9:30 – 10:00	***Arrival/ coffee and tea***
10:00 – 10:15	Welcome and introductions
10:15 – 11:00	Background and context (Chris Kerr, MPI) Q & A
11:00 – 12:00	Identify existing and potential tools/options for agricultural GHG emissions estimation and reporting. Plenary discussion
12:00 – 12:30	Confirmation of assessment criteria
12:30 – 13:15	***Lunch***
13:15 – 14:45	Assess each tool/option against the agreed criteria (Green, Yellow, Red with underpinning narrative)
14:45 – 15:00	***Afternoon tea***
15:00 – 15:45	Plenary discussion to agree on assessments and narratives
15:45 – 16:00	Next steps (AgResearch and MPI)
16:00	Close of workshop

Photos of the assessment matrices completed by the three breakout groups






1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11.
5. Farm specific eg Overseer.
6. + econ tools.
1. Look up tables.
2. Lookup + mitigation.
3. Crude model eg Lincoln
4. AIM

7.2 Collation of workshop findings on assessment of six GHG tools/options

Legend: green=positive; yellow=neutral or intermediate; orange=negative; blue=don't know; white=not assessed

Tool:	*Group*	Criteria: 1. Goodness of fit	2. Captures current and future mitigation options	3. Flexibility to include C	4. Data requirements	5. Trade offs/benefits	6. Readiness	7. Can support product claims	8. How big is transition to its use?	9. Ease of use/RP support needed?	10. Transparency	11. Ability to capture changes in stock #s and land area
1. GHG emissions per unit of product or per animal	*1*	Poor accuracy	No	No	Should be	Cheap	Yes Ready	Not ready = National are specific farm ≠ o	Simple	Yes	Yes	Stock Yes
						Simple not specific to farm						Land area No
	2	Not fair to all producers Doesn't reward action	Doesn't capture individual action Crude	Requires another look-up table/tables	Easy to get data	Depends on obligation point - if processor: good; if farm gate: bad	Could do tomorrow	Not robust enough		Very easy in theory No addition of data collection	100% transparent	100% flexible
		Works better for CH_4 than N_2O			Challenge around verification - animal numbers	Low cost						
					Tracking stock for red meat sector and dairy sector - tricky							
	3	Not an average. Distribution is actually wide	Can't attribute mitigation	Can't	Simple but still hard to verify animal numbers	Cheap	Could develop in months (relatively quickly)	Not credible	Easy for wrong reasons	Easy but for what purpose? What decisions can be made?	Depends on how it's designed/built	Yes
						But different from N leaching; No ability to ascertain pollution swapping			relatively easy but could lead to wrong decision			
2. Option 1 but with reductions for adopting known mitigations	*1*	Poor accuracy	Yes	No	Mitigation data required	Cheap	Need abatement course and science	Not ready = National are specific farm ≠ o	Simple	Yes	Yes	Stock Yes
						Simple not specific to farm						Land area No
	2	Fairer than Option 1	Can capture at basic level (Verification issues)	Fairer than Option 1	Needs more data - mitigation and use (compared with	Fairer than Option 1	Haven't got all data for mitigations	Without verification High cost		Very easy in theory Limited need for RP	Transparency 100% (MPI publish Efs etc)	Fully flexible
										Maybe not so easy in practice (eg from forestry to ETS)		
	3	Not an average. Distribution is actually wide	Limited mitigation possible with check box	Can't	Simple but still hard to verify animal numbers	Cheap	Could develop in months (relatively quickly)	Not credible	Easy for wrong reasons	Easy but for what purpose? What decisions can be made?	Depends on how it's designed/built	Yes
						But different from N leaching; No ability to ascertain pollution swapping			relatively easy but could lead to wrong decision			

7.2 continued (green=positive; yellow=neutral or intermediate; orange =negative; blue=don't know; white=not assessed)

Tool:	Group	Criteria: 1. Goodness of fit	2. Captures current and future mitigation options	3. Flexibility to include C	4. Data requirements	5. Trade offs/benefits	6. Readiness	7. Can support product claims	8. How big is transition to its use?	9. Ease of use/RP support needed?	10. Transparency	11. Ability to capture changes in stock #s and land area
3. Crude energy requirement model (e.g. Lincoln C footprint calculator) or combination of lookup table for DMI and fixed CH_4 yield value	1	Not fit for nitrous	No	No	Yes	Very limited	Ready for use by farmers	Not sure. Pretty flimsy support of DMI to CH_4; number claims.	transition easy - animals numbers in + x out	In use now	Should be/could be ? Maybe	Stock numbers - depends on boundaries and time scales (stock on/off)
		Ok for CH_4										Land area change - change to baseline
	2	Some limitations, eg, no environmental factors	Captures limited mitigation	Gives more complete picture, including energy, forestry companies	Relatively easy to obtain		Available today	Supports product claims		Easy (app on phone) RP not required	We assume it is fully transparent, if not easily could be	Fully flexible
		Good alignment with national inventory	(1.2 & 2.2 as well) Doesn't capture change over time (consistency)	Static								
	3	More detailed compared with options 1 and 2. But worry about having the worst features of both look-up table and models										
4. Energy requirements and nitrogen model using default values and approaches (e.g. Agricultural Inventory Model; AIM)	1	Farm specific - allows specific farm management info	OK for CH_4; missed N_2O; management changes	No	More data needed- some will be har-der than others, eg, dairy vs remote.	No trade offs, no pollution swapping - some co-benefits	Not ready for use. Need user interface	Is a recognised tool but will have to be a matching up. Verification needed	Big - no-one currently (except MPI & AGR) and not known	bit unknown - conceptually could be easy	Transparent - engine findable	Stock/numbers Yes
		Farm type specific - not geospatial (weather, soils)			Overseer to hill country; Over time, better data will come	It is a recognised tool						land area - No
	2	Will be as good as data input is	Captures simple mitigation	Possible	Available 3 data points required; numbers, products, N fert		Not ready right now - would need user interface development	Supports product claims (see also 4.10)		Easy (if user inter-face is good; see under 'Readiness'); RP not required (if interface is good)	Subject to expert review annually (UNFCCC) process)	Fully flexible and times series consistency
		Aligns with NIR										
	3	Nearly a green	Limited to the specific farm data inputs; Not as flexible as Overseer	Not spatial so hard to include riparian and poplar poles	Monthly livestock nightmare to verify	Does not deal with N in water; A holi-stic application for farm environmen-tal impacts more difficult to do	Interface needs heaps of work	Okay				
						International inventory alignment						

7.2 continued (green=positive; yellow=neutral or intermediate; orange =negative; blue=don't know; white=not assessed)

Tool:	Group	1. Goodness of fit	2. Captures current and future mitigation options	3. Flexibility to include C	4. Data requirements	5. Trade offs/benefits	6. Readiness	7. Can support product claims	8. How big is transition to its use?	9. Ease of use/RP support needed?	10. Transparency	11. Ability to capture changes in stock #s and land area
5. Farm-specific model – energy requirements and nitrogen model using farm-specific values and approaches (e.g. Overseer)	1	Farm specific? Less uncertain than others. Estimates what is there ? = for equitability (is how its used)	Yes we hope so	Yes	Should be avail-able for farm specific but some bits may be not, eg, wetland and subjective decisions	Should be able to. Overseer does for flow-on impacts $ - $$$; Maybe u $$ to use for set up/RP	One is available that is available; Overseer; no other known	Able to support some claims (for farm) and feeds into wider footprint certification	Still significant portion of farmers not engaged in such a tool; New to Overseer wouldn't be able to use FM without help	Overseer: better and getting better; May need consultants especially for mitigations; Not all consultants good on all farm systems	Overseer transparent models published	Can - it had better
					Does need more data but should be available; may be challenging for some data at least in future, eg, GPS for fertiliser appln				For those already using Overseer not a biggie; FM - make it more usable			
	2	Good fit with NIR			Data requirements are extensive - harder and costly to collect							
	3	Detailed estimates and allows for miti-gations; More detail avoids over-estimating emission for some farmers	More flexibility the better	Spatial data may help capturing on-farm vegetation	Depending on how models are designed. Hard to verify monthly stock numbers	Already used; Can do N leaching and fert recs; Richer understanding of farm systems - better advice	If OVERSEER	Assume move into insights available	Heaps of resources to roll out nationally	OVERSEER FM is better	Generally complex models are hard to understand even if open; Can be "transparent" via expert review	Yes
						Trade off: Time, Costs, Resources, Verified/auditing	If not OVERSEER				Can be "Transparent" via expert review, etc	
6. Option 5 plus economic/financial impacts of mitigations	1	Good to have not a priority for now	Good to have not a priority for now	Good to have not a priority for now	Good to have not a priority for now	Good to have not a priority for now	Good to have not a priority for now	Good to have not a priority for now	Good to have not a priority for now	Good to have not a priority for now	Good to have not a priority for now	Good to have not a priority for now
	3	Yes	Allows scenario analogy - easy to adopt	Yes	more financial data makes harder. Could be yellow Depends on the level of detail	Builds on existing analysis. Can use with bank	Needs development Even FARMAX not ready	NA		Okay	As a tag-on to 5	As a tag-on to 5

7.3 Results of review of existing reports and information

Numbers in red refer to the criteria used in the workshop assessment. Please note that criteria 7 (can support product claims) is not included as none of the reports specifically discussed this criterion. (grey=no information available in the reviewed reports)

	Criteria								
Tool/option	1.[#] Goodness of fit/ uncertainty[1]	2. Current and future mitigations[2]	3. Flexibility to include carbon[3]	4. Data requirements[4]	5. Co-benefits/ Trade-offs[5]	6. and 8. Readiness and transition[6]	9. Ease of use/ RP support needed[7]	10. Transparency[8]	11. Can capture changes in stock or land[9]
1. GHGs/product or animal	Emission factors per head or per product are estimated using the national inventory model and need to be updated on an annual (or rolling average) basis to account for changes to the inventory methodology. If emission factors are calculated based on an assuming a static national herd, there will be a 'lag effect' in the calculated values if the size of the national herd is either increasing or decreasing (Journeaux 2019). This issue could be minimised by using a rolling average to smooth the changes in the emission factor. The methodology proposed by Journeaux (2019) for calculating emission factors for each of the different stock types results in significant differences between them, and the ".. disparity between the stock types is not that obvious". "Until this apparent anomaly between the stock types is resolved, the recommendations is to use the 'cattle' emission factors for all main livestock classes (Journeaux 2019). This option does not capture differences in feed	NZPC (2018)$ comments that a system were emissions are estimated based on national averages for milk and meat (or amount of N fertiliser applied) only incentivises reduction in output and is and therefore provides a blunt price signal to reduce emissions. Little direct incentive to change other management practices.	Not specifically commented on in any of the reports but this is, by definition, not possible.	Journeaux (2019) commented on this in relation to GHG per unit of fertiliser N applied. It would be easier to use a weighted average value for all N fertiliser types. The main drawback is that it "blunts the incentive to use lower GHG-emitting fertilisers, by effectively 'hiding' the cost advantage of these fertilisers." However, differentiation by N fertilisers is administratively more complex.	Easier to implement and least costly (NZPA, 2018)[$] Cost to implement processor point of obligation estimated at ~ 3M/annum (BECA, 2018)				

	conversion efficiency between individual animals								
2. As per 1. but include GHG mitigations	The assessments for option 1 equally apply to this option. No reports specifically discuss this option in the context of the assessment criteria. However, it is referred to in a few reports (e.g. de Klein and Kelliher, 2018 and NZPC, 2018) as an option that has the simplicity of option 1, yet provides some incentives for adopting mitigation strategies. Rebates can be given based on national average assessments of the effect of the mitigation options, or a farm-specific model could be used to assess farm-specific effectiveness of the mitigation options. The latter could help inform the level of rebate for each GHG reduction practices and the on-farm value of implementing the GHG reduction practices (de Klein and Kelliher, 2018).								
3. Crude ME requirement model	There are no reports discussing this option. However, we checked the LU Carbon Calculator on-line. This model requires basic farm-level information (e.g. animal numbers, production, fertiliser use etc) but it is not clear how the model uses this input information to estimate the GHG emissions. The description states it uses the inventory emission factors, but does not give the actual values, so it is not possible to check what values are used.								
4. Based on ME requirements/ DMI (e.g. AIM)	**Uncertainty** No estimation of uncertainty directly available in AIM. Indirect estimates of the uncertainty of its emission estimates have been made based on estimating the uncertainty of ME requirements. **Goodness of fit** National average values. Does not provide farm-specific values	AIM can be, and has been, used to assess the impact of a range of current (Kelliher et al 2015) and future (Reisinger et al. 2017, 2018) mitigation options. Key examples include: CH_4 vaccine, CH_4 or N inhibitors, low GHG animals, reduced N fertiliser use, fewer more efficient animals.	No (n/a for current inventory)	Sourced from government (MPI) and industry bodies (e.g. Stats NZ, MPI) with data entry QA/QC by MPI. This data is readily available to the existing MPI users. Most required data are likely to be available at on-farm scale, though this was not commented on in the reports.	Flexibility by experts to assess many mitigations that aren't available now (Reisinger et al. 2017). No economics. Does not capture impacts on H2O quality in waterways or catchments.	While AIM is used by government (MPI) and others report its use (e.g. Reisinger et al. 2017), it's not ready for widespread use to assess on-farm GHG emissions.	AIM as main example of this approach is for MPI use only so "ease of use" only relevant for MPI staff, and some researchers who've used it for MPI specific tasks (e.g. Reisinger et al. 2017).	This is the approach used by AIM, and forms basis of that used by Overseer. Documentation for AIM publicly available via MPI website detailing methodology and equations used for calculating estimates of ME requirements and DMI and emissions. Many supporting technical reports also available via MPI website.	Land area –AIM does not use area. Stock numbers – AIM has been used for scenario analyses where (national) stock numbers are changed. This is one of possible mitigation options reported in some of reports.
5. Farm specific option (e.g. Overseer)	**Uncertainty** Currently no built-in estimation available in Overseer. Concerns raised through most reports, including several examining perceived short-comings, and note desirability (e.g. PCE, 2018: Important issues remain to be clarified concerning the uncertainty that attaches to its outputs"). No published uncertainty analyses. Discussions stop at estimation of uncertainty of ME requirements, as this drives DMI and subsequent biological emissions. **Goodness of fit**	Majority of current mitigations can be implemented in current version (6.3.0) of Overseer. Many reports cite results using common (mostly farm management level) options. Reisinger et al. (2017, 2018) used Overseer in conjunction with another farm systems modelling tool, Farmax (which doesn't directly estimate GHG emissions). Options that can be captured in addition to those listed	Reisinger et al. (2018) discusses options to represent C, but goes on to comment about lack of information and data (pg. 38)" There is a lack of farm-based tools to estimate soil carbon levels or to identify what can be done to enhance soil carbon or prevent its loss. The long-term	Minimised in interest of ease of user data entry (as originally developed for use by farmers and consultants). Concerns raised through most reports around transparency (of calculations) and quality of data used. User data entry, with documented data input standards to follow, but there remains unknown QA/QC on actual data values. Currently (6.3.0) possible in theory to verify	Overseer is already being used (e.g. NZPA, 2018$ and de Klein et al. 2016). Can also provide farm scale losses to water. Legacy versions of Overseer will no longer be available from 1 July 2019, and users will be charged for using the new version (FM). No economics. NZPA (2018) $: "It is not simple to accurately estimate a farm's	Overseer (6.3.0 and earlier versions) is has been available for some years, and is widely used. Many of reports include reference to Overseer, or solely focus on Overseer alone. Movement to a new version ("FM") from July 2019 (PCE, 2018; pg. 91, footnote 199), but no reports discuss its usage.	All reports and studies to date refer to Overseer 6.3.0 and earlier versions. See PCE, 2018; pg. 91, footnote 199.	Also, see above (4). Proprietary nature of Overseer dealt with at length in reports. E.g. (PCE, 2018: "source code and some proprietary algorithms and technical manuals"). While this is mostly driven by discussion of its use in a regulatory environment, it also applies to use for estimating on-farm GHG emissions. BERG (2018) (§4.3 pg. 33) outlines steps to remain aligned with AIM,	Overseer can specify changes to both stock numbers and land area. This ability has been used to investigate mitigation options (e.g. Kelliher et al. 2015 and Reisinger et al. 2017). Reisinger et al. (2017) used Farmax to help with stock number calculations, and then Overseer (using Farmax outputs) to estimate GHG emissions.

	As option 4, but more detail to specify farm specific and system options especially manure management systems. AIM used as basis for comparison, mostly as Overseer uses similar methodology adapted to the farm level (Reisinger et al. 2018), §4.3, pg. 32). Most reports comparing AIM and Overseer estimates cite differences (Rollo et al 2018; Kelliher et al. 2015). de Klein & Kelliher, (2018; pg. 113) states the “Need to see peer reviewed literature around the accuracy of Overseer (or what model is used) in predicting GHGs”	under tool 4, include: low GHG feeds, enhanced manure management, once-a-day milking, land-use changes/trees (Reisinger et al. 2018) Current mitigation options **not** able to be implemented in Overseer were (Kelliher et al. 2015) apply N fertiliser with urease inhibitor and apply effluent when N losses lowest. Other mitigations may require software changes. Effect of future mitigations necessarily unknown, ability to assess using “What ifs" may be possible even if not directly implemented in Overseer.	nature of changes to soil carbon stocks means that significant improvements to the monitoring system used to report on domestic greenhouse gas emissions will require several decades of data”	inputs, but with new (FM) version this is unknown. “Inputs” extends to GHG emission factors (EFs) which have in some reports been commented on as not in alignment with AIM. Proprietary interface (mentioned in reports) limits ability to check and verify data.	emissions.” and “more difficult to administer with potentially high transaction costs [..than option 1 or 2]. These costs could outweigh the benefits of a farm-scale system, especially given that limited mitigation options are available”. Gluckman (2018): “[Overseer] … is subject to a range of uncertainties and has other issues that limit its usefulness as a direct regulatory tool.” BECA (2018): Cost of imple-menting farmer point of obligation estimated at ~40M/annum			including the establishment of a working group.	

[#] these numbers refer to the assessment criteria from the stakeholder workshop, with criteria 7 (ability to support product claims) not included here. [$] NZPC (2018) discusses different options for ‘point of obligation’ for agricultural emissions. The report does not directly discuss pros and cons of tools/options for accounting for emissions, but assessments can be inferred.

Explanation of criteria (either as described by MPI or as discussed at the stakeholder workshop):

[1] Based on the review of written reports and information available, assess the goodness of fit for estimating absolute emissions, and, where available, an uncertainty range.

[2] Is the tool flexible and future proofed enough to recognise and incorporate current and potential emission mitigation activities? Can the tool be updated as new CH_4 and N_2O mitigation options are identified?

[3] What flexibility does the tool have to allow for on-farm energy use, soil carbon and forest sinks to be incorporated?

[4] What are the input and data requirements? How available is the data to farmers, processors, or policy makers? Are the inputs independently verifiable? How difficult are they to verify?

[5] E.g. is the tool/option already used for other purposes (e.g. Overseer for water quality), or are there any trade-offs in terms of e.g. cost

[6] What is the readiness of this tool (e.g. can it be used now, or does it need more development)? How big it the transition towards using this tool (e.g. can be used immediately vs tools is ready now but needs additional systems/processes to be put in place before can be used?

[7] Can be easily adopted by farm owners/land-users vs needs expert input from advisors.

[8] Are the working and underlying assumptions of the tool fully documented? Is it fully transparent how the emissions are calculated?

[9] Does the tool have the ability to deal with changes in stock numbers and land area?.