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Review of Models Calculating Farm Level GHG Emissions

Prepared for He Waka Eke Noa

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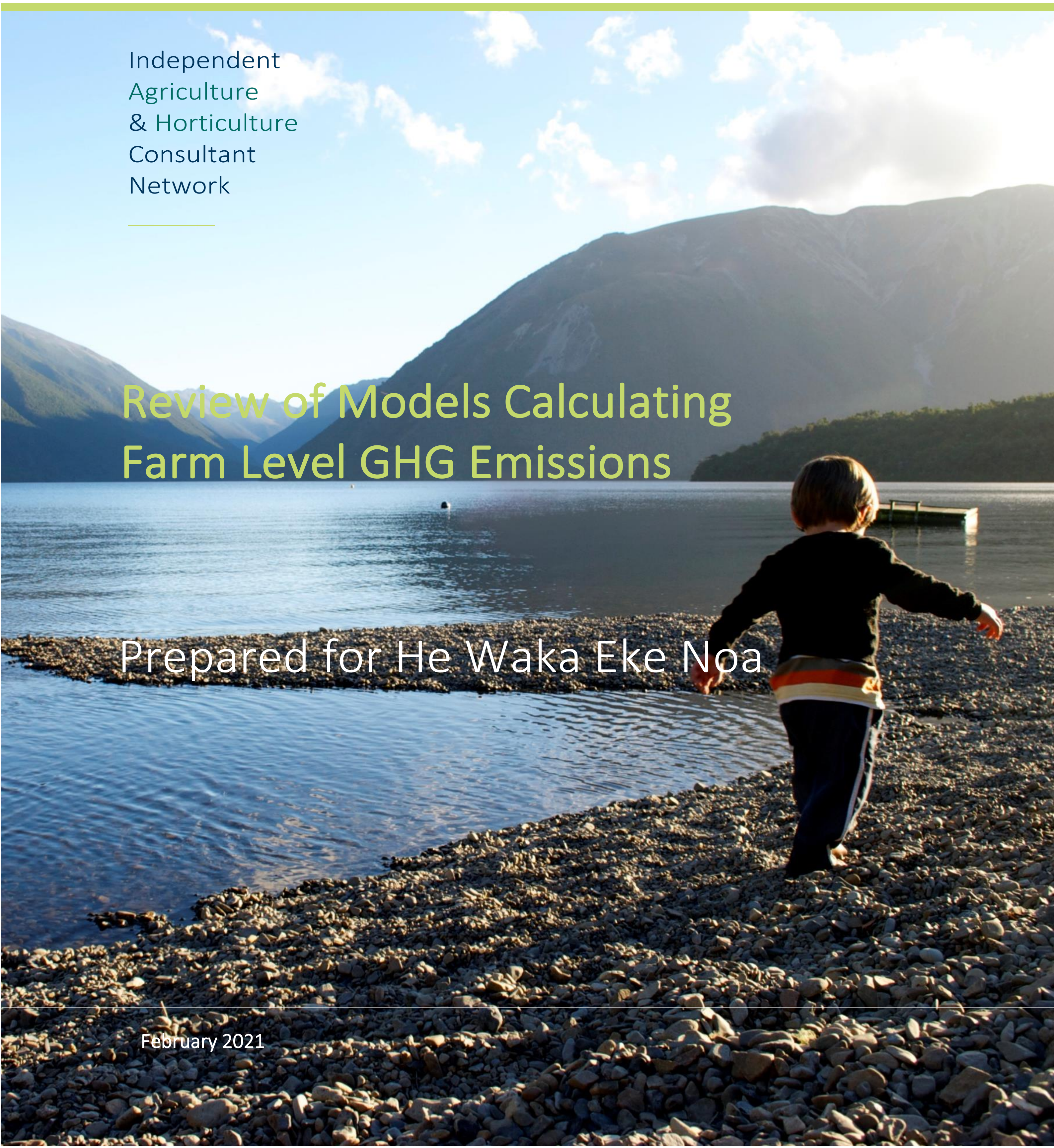

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Abbreviations

% methane – this refers to the percentage of methane in terms of total greenhouse gases, which is a combination of methane and nitrous oxide.

AR4 – Fourth Assessment Report by the IPCC.

CH_4 – Methane.

CO_2 – Carbon dioxide.

CO_2 e – Carbon dioxide equivalents. Often expressed in kilograms (kg CO_2 e) or tonnes (t CO_2 e).

DMI – Dry Matter Intake. Amount of feed animal intakes. See KgDM.

GWP_{100} – Global Warming Potential at 100 years. This is the metric used in the Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC).

GHG – greenhouse gas.

ha – hectares.

KgDM – Kilograms of Dry Matter. Unit used to measure feed quantity.

kg/ha CH_4 - kilograms per hectare of methane. This metric is calculated by the total amount of methane produced on-farm divided by the total farm area.

kg/ha N_2O – kilograms per hectare of nitrous oxide. This metric is calculated by the total amount of nitrous oxide produced on-farm divided by the total farm area.

KgMS – kilogram of milk solid. The solid constituents of milk. It is used as a production metric on dairy farms.

ME – metabolisable energy. Unit for assessing feed quality and expressed as units of metabolisable energy per kilogram of dry matter in feed.

MfE – Ministry for the Environment.

MPI – Ministry for Primary Industries.

N – Nitrogen. Fertiliser component and a proxy to measure the protein content of a feed.

N_2O – Nitrous oxide.

S&B – Sheep and Beef.

1.0 EXECUTIVE SUMMARY

This report was commissioned by He Waka Eke Noa, as part of their five-year programme to implement a framework by 2025 to reduce agricultural greenhouse gas emissions and build the agriculture sector's resilience to climate change.

The programme has two early emissions reporting milestones:

- By the end of 2021, a quarter of farmers and growers in Aotearoa New Zealand know their annual total on-farm greenhouse gas emissions. In practice this means a person responsible for farm management holds a documented annual total of on-farm greenhouse gas emissions, *by methods and definitions accepted by the He Waka Eke Noa Steering Group.*

- By the end of 2022, 100 percent of farmers and growers know their annual total on-farm emissions.

In order to achieve these milestones, a draft set of minimum specifications for methods was developed by the Emissions Reporting Workstream of He Waka Eke Noa. In addition, a set of recommendations on presentation of the results were developed. This report was commissioned to assess the performance of seven models and calculators capable of calculating biological greenhouse gas (GHG) emissions against the set of draft minimum requirements for methods, and the recommended presentation of results.

The methodology of assessment meant that the details of eight farming systems were provided by the relevant industry body to the model providers, who then ran the details of the farms through their models and provided a summary of inputs and outputs to be assessed.

Models by farm type are summarised below:

Models	Waikato Dairy	Canterbury Dairy	High Country S&B	Southland Intensive S&B	S&B with dairy grazers	Deer	Arable Cropping	Citrus
Alltech	x	x	x					
E2M	x	x						
Farmax	x	x	x	x	x	x		
Fonterra/AIM	x	x						
Horticulture NZ								x
Ministry for the Environment	x	x	x	x	x	x	x	x
Overseer	x	x	x	x	x	x	x	

These were then assessed relative to the minimum requirements (Section 3.0), and the clarity of the outputs.

Collation of the resulting GHG emission figures for the same farm type across the different models (Section 6) showed some degree of variation across the different models. In part this is due to differences within models around key factors such as Dry Matter Intake (DMI), Metabolisable Energy (ME) and the percentage of nitrogen (% N) values of feed, and in part by differing assumptions about the supplied input data and in some cases, ‘operator error’.

There were also some minor presentational issues with some of the models, e.g. not recording farm location or the area of the farm, which are currently part of the minimum specifications.

Forestry sequestration (as is currently recognised within the ETS) is included within three of the models (Alltech, MfE and Overseer). Farmax is shortly to release an updated version which includes forestry sequestration.

Classification of the models, as to their level of ‘detailedness’ is:

	Simple	Intermediate	Detailed
Alltech		✓	
E2M		✓	
Farmax			✓
Fonterra		✓	
Hort NZ	✓		
MfE	✓		
Overseer			✓

Coverage of the models by farm type are:

	Dairy	Sheep & Beef	Deer	Horticulture	Arable
Alltech	✓	✓			
E2M	✓	✓			
Farmax	✓	✓	✓		
Fonterra	✓				
Hort NZ				✓	
MfE	✓	✓	✓	✓	✓
Overseer	✓	✓	✓	✓	✓

Summary of model outputs compared with recommended outputs

Emissions source	Enteric Methane (CH_4)	Effluent Storage and dung deposited onto land (CH_4)	Total Methane from livestock	Effluent Storage (not effluent applied to land) (N_2O)	Agriculture Soils (N_2O)			Total Nitrous Oxide Emissions from livestock and fertilizers	CO_2 from application of Urea fertiliser to soil (if included in tool)
					Simple Tools (single value encompassing direct & indirect)	Intermediate & Detailed tools: separates direct from Indirect (leaching)	Intermediate and Detailed tools: separates direct from Indirect (volatilisation)		
Alltech	✓	✓	✓	✗	NA	✓	NA	✓	✓
E2M	✓	✓	✓	✗	NA	✓	NA	✓	✗
Farmax	✓	✓	✓	✗	NA	NA	✓	✓	✓
Fonterra/AIM	✓	✓	✓	✓	NA	✓	NA	✓	✗
Horticulture NZ	NA	NA	NA	NA	✓	NA	NA	✓	✓
Ministry for the Environment	✓	✓	✓	✓	✓	NA	NA	✓	✓
Overseer	✓	✓	✓	✓	NA	NA	✓	✓	✓

Summary of models relative to draft minimum specifications and recommended presentation (detailed in section 3).

	Draft Minimum Specs for Methods				Presentation (area, address, system, context)					
	Valid emission factors (referenced)	Minimum inputs (livestock/fertiliser)	Model Structure/ equations	NZ Peer reviewed research for mitigation or sequestration	Reporting of GHG - metrics used	Area	Address or unique identification number	Farm system	HWEN context & sequestration statement	Tag if mitigations used are not in the NZI
Alltech	✓	✓	NIS	NIP	✗	✓	✓	✓	✗	✓
E2M	✓	✓	NIS	NIP	✗	✗	✗	✗	✗	NA
Farmax	✓	✓	NIS	NIP	✓	✓	✗	✓	✗	NA
Fonterra/AIM	✓	✓	NIS	NIP	✓	✓	✗	✓	✓	NA
Horticulture NZ	✓	✓	NIS	NIP	✓	✓	✓	✓	✓	NA
Ministry for the Environment	✓	✓	NIS	NIP	✗	✗	✗	✗	✗	NA
Overseer	✓	✓	NIS	✓	✓	✓	✓	✓	✗	NA

Key: ✓ = meets specification or recommendation ✗ = does not meet specification or recommendation NIP = No information provided NIS = Not in scope NA = not applicable

Based on the data supplied, all of the models appear to adequately calculate farm-level GHG emissions.

In noting this, not all models met the recommendations on presentation of results:

(i) Alltech, E2M, Farmax, did not explicitly show emissions for effluent storage and/or CO_2 from urea applications. It is possible some may allow for these factors (e.g. Farmax has an allowance for anaerobic lagoons built within it) but don't explicitly show it.

(ii) E2M and MfE models did not include the farm area.

(iii) E2M, Farmax, MfE models did not include a farm address or unique farm identifier.

(iv) The Fonterra/AIM method and the Hort NZ model were the only providers to include context around He Waka Eke Noa.

2.0 BACKGROUND

He Waka Eke Noa is an Industry/Government/Iwi five-year programme that is working together to implement a framework by 2025 to reduce agricultural greenhouse gas emissions and build the agriculture sector's resilience to climate change.

Through this framework farmers and growers will be empowered to measure, manage and reduce on-farm emissions; recognise, maintain or increase integrated sequestration on farms; and adapt to a changing climate.

As part of this programme, methods and definitions accepted by He Waka Eke Noa for farm-scale reporting for GHG emissions (from livestock and synthetic nitrogen (N) fertiliser), must be established within a time frame which enables, by December 2021, 25% of farms to hold a documented annual total of GHG emissions, and by December 2022, 100% of farms.

Tools for estimating and reporting farm scale GHG emissions will be necessary to meet these milestones. An assessment of the available stock of tools is required to ensure reporting can be achieved reliably while meeting accepted methods and definitions for reporting GHG emissions.

For the He Waka Eke Noa programme on-farm greenhouse gas emissions sources are livestock (ruminant animals, pigs, horses, or poultry) and fertiliser (synthetic fertiliser containing nitrogen)[1]. Therefore, the greenhouse gases which the on-farm reporting tool will need to include as a minimum are livestock (methane and nitrous oxide) and fertiliser (nitrous oxide and carbon dioxide).

3.0 OBJECTIVES

The objectives of the review therefore were to assess the performance of the various models against the draft minimum requirements as specified by He Waka Eke Noa:

1. Draft method requirements:

   (i) Use emission factors sourced from the National Inventory, or another valid source (e.g. International default).

   (ii) Minimum set of required inputs:

   - Livestock numbers (by species) either using monthly values or for simple tools a weighted annual average.
   - Amount of synthetic nitrogen fertiliser.

   (iii) Have a logical and internally consistent model structure and set of equations which reference appropriate sources of key parameters, algorithms, and data inputs[2].

[1] As defined in the Climate Change Response Act 2020

[2] It was not possible to 'deconstruct' the models supplied to determine equations/algorithms which drove the models, and in several cases the authors only had the outputs from the models. In this respect, it was not possible to determine model structure and any internal consistencies.

(iv) Use peer reviewed research to accompany any methods for mitigation or sequestration of emissions.

2. Recommendations on presentation of on-farm GHG emissions requirements

   (i) Greenhouse gas emissions should be displayed as separate gases (methane, nitrous oxide and carbon dioxide) and are encouraged to be displayed as a weight of gas.

   (ii) Total greenhouse gas emissions should also be displayed in GWP100 values from the Fourth Assessment Report for consistency with New Zealand's National Inventory Reporting: carbon dioxide (1); nitrous oxide (298); methane (25).

   (iii) Alternative equivalency metrics may also be provided.

   (iv) The current use of GWP100 does not pre-empt future recommendations by He Waka Eke Noa Steering Group on a metric that may be adopted as part of the He Waka Eke Noa Programme, in particular as part of any farm level emissions pricing scheme.

   (v) Greenhouse gases emissions should be reported from livestock and fertiliser as set out in Table 1 below.

3. Recommendations on presentation of information to the farmer[3]

   (i) Total area of farm

   (ii) Physical address or unique farm identifier of the property and the person who is responsible for providing the on-farm data which has been used by the tool.

   (iii) Type of agricultural farm (e.g. dairy, beef, lamb, cropping, mixed etc.).

   (iv) Context for greenhouse gas emissions in terms of the He Waka Eke Noa Primary Sector Climate Change Partnership, including a statement that He Waka Eke Noa is working on determining methods for calculating on-farm sequestration by 2022 (and which may vary from those currently incorporated in the tool).

   (v) A tag or disclaimer if mitigations are used which are not incorporated in the New Zealand Greenhouse Gas Inventory.

The models/calculators are then classified as:

- Simple tools – uses standard input metrics.
- Intermediate tools – uses national average assumptions.
- Detailed tools – uses detailed farm specific activity data and additional sophistication.

[3] The workstream is aware of the need to assure farmers that their privacy is protected. The report to the farmer however would ideally include all the specified information. Any information exchanged between farmers and tools providers will be subject to privacy and confidentiality agreements between those parties, if applicable.

Table 1: *Emissions sources as an output of the tool*

Emissions source[4]	Enteric Methane (CH_4)	Effluent Storage and dung deposited onto land (CH_4)	Total Methane from livestock	Effluent Storage (not effluent applied to land) (N_2O)	Agriculture Soils (N_2O)			Total Nitrous Oxide Emissions from livestock and fertilizers	CO_2 from application of Urea fertiliser to soil (if included in tool)
					Simple Tools (single value encompassing direct & indirect)	Intermediate & Detailed tools: separates direct from Indirect (leaching)	Intermediate and Detailed tools: separates direct from Indirect (volatilisation)		
Livestock Emissions									
Dairy Cattle	✓	✓	✓	✓	✓	✓	✓	✓	✗
Beef Cattle	✓	✓	✓	✗	✓	✓	✓	✓	✗
Sheep/lambs	✓	✓	✓	✗	✓	✓	✓	✓	✗
Deer	✓	✓	✓	✗	✓	✓	✓	✓	✗
Swine	✓	✓	✓	✓	✓	✓	✓	✓	✗
Poultry	✗	✓	✓	✓	✓	✓	✓	✓	✗
Horses	✓	✓	✓	✗	✓	✓	✓	✓	✗
Llama and alpaca	✓	✓	✓	✗	✓	✓	✓	✓	✗
Other Livestock Emissions	✓	✓	✓	✓	✓	✓	✓	✓	✗
Fertiliser Emissions									
Total Synthetic Nitrogen Fertiliser	✗	✗	✗	✗	✓	✓	✓	✓	✓

[4] Note that output reports do not need to cover all these types of livestock. Where a tool is designed only for a particular sector e.g. pork, only the pork row would be included in the output.

4.0 METHODOLOGY

Eight farm types were specified, with the details of the farms provided by the relevant industry body (e.g. Dairy NZ provided the details for the dairy farms, Beef + Lamb New Zealand the details for the sheep & beef farms, Deer Industry New Zealand, the details for the deer farm, etc). These specifications were provided to the seven model providers who then in turn provided the relevant input/output data from their models relative to the farm type modelled.

Farmax, Overseer, MfE, and Horticulture NZ provided the electronic files of their models, while Alltech, Fonterra, and E2M provided a copy of the model output/report.

Table 2: Farm types modelled by model

Models	Waikato Dairy	Canterbury Dairy	High Country S&B	Southland Intensive S&B	S&B with dairy grazers	Deer	Arable Cropping	Citrus
Alltech	x	x	x					
E2M	x	x						
Farmax	x	x	x	x	x	x		
Fonterra/AIM	x	x						
Horticulture NZ								x
Ministry for the Environment	x	x	x	x	x	x	x	x
Overseer	x	x	x	x	x	x	x	x

Assessment of the models was achieved by splitting the farm types across three assessors, so that they could then view the same farm type across the different models. An assessment criterion scoring sheet was developed, relative to the minimum set of requirements for inputs and outputs (refer Appendix 1/2/3). This was used to help assess the different models for the purpose of classification, i.e. simple, intermediate and detailed. The classification and scoring do not infer the suitability or effectiveness of each tool as it depends on the purpose of use. To assess mitigation options specific to a farm, for instance, more information is required.

During the assessments, the model providers were approached directly as to any issues that required clarification.

Once the individual assessments were complete, the three assessors met to discuss and compare the results. Tool providers' feedback was sought on the draft commentary for their model, and feedback incorporated.

A draft report was provided through to He Waka Eke Noa, which was then finalised following some additional comments provided.

5.0 SUMMARY OF MODELS

A summary of the various models assessed is outlined below.

5.1 AllTech E-CO_2

The Alltech E-CO_2 model is a proprietary model, based around the IPCC tier 2 framework. They have separate models covering dairy, lamb, beef, poultry, pigs, dairy goats. A separate model is also available to calculate forestry carbon sequestration.

5.1.1 Inputs:

The main inputs into the model are:

- System type.
- Livestock data: average stock numbers by type, liveweights, sales and purchases, production.
- Effluent system for dairy farms.
- Crop production: type, area, yield.
- Supplementary feed inputs.
- Fertiliser input.

5.1.2 Outputs

The outputs from the model are presented in a report to the farmer, showing:

- A summary of the input data compared to the NZ average.
- CO_2e emissions, split into components of CH_4, N_2O, and CO_2. There is a graphic which shows the source of the different gases. In the report provided, these figures were all shown on an intensity basis (kg/kgMS or kg/kg meat). For New Zealand, the requirement is for the information to be in an absolute form, i.e. kg CO_2 e/ha. In discussion with Alltech, they indicated the intensity basis approach is based on other country requirements, and they could, for New Zealand, easily show the information in absolute terms.
- Can include carbon sequestration.
- A range of information on what drives GHG emissions.

As noted, the model is a proprietary one, operated by Alltech for their clients.

5.2 E2M

The Enviro-Economic Model (E2M) is based on a linear-programming (LP) platform and uses marginal cost/benefit relationships to drive its economic optimisation. This can then be coupled with changes (or restrictions) in environmental impact (Nitrogen-leaching, GHG emissions).

The model covers dairying and sheep and beef.

5.2.1 Inputs

Key inputs are:

- Financial data – pay-outs, farm working expenses etc.
- Pasture growth.
- Supplementary feed inputs.
- Nitrogen fertiliser inputs.

5.2.2 Outputs

For greenhouse gas emissions, the key output is total CO_2 e, split between CH_4 and N_2O.

The model is proprietary, used by the consultant with clients.

5.3 Farmax

FARMAX Pro is a web-based farm system and economic simulation model, which indicates the biological feasibility of a livestock system and allows users to evaluate the economics of alternative livestock policies. The model calculates the required feed demand for a modelled livestock system within the restraints of input pasture growth rates, supplementary feed inputs, and animal performance data. It covers pastoral farming systems; dairy, sheep & beef, and deer.

It can also incorporate forestry blocks, although currently this does not include calculation of carbon sequestration. A carbon sequestration model has been developed, based on current ETS requirements, which is due to be released shortly.

5.3.1 Inputs

Farmax requires detailed inputs, e.g.

- Stock numbers by type, age, liveweight, liveweight gain, production parameters.
- Pasture growth rate, supplementary feeds by type and amount, crop areas by type and yield, pasture nitrogen fertiliser inputs.
- Financial parameters such as pay-outs/schedules, farm working expenses.

5.3.2 Outputs

Key outputs are:

- Whether the farm system is biologically feasible (i.e. feed demand =/< feed supply).
- Farm profitability.
- Production levels.

From a greenhouse gas perspective: CO_2 e/ha, broken down by CH_4 and N_20, and the source of each of the gases. It also shows CO_2 e from nitrogen fertiliser application. It can show CO_2 e/ha on a total ha, effective ha, or pasture only (i.e. excluding crops) basis.

Farmax is commercially available to advisors and farmers on a fee-for-use basis. Training is required to operate the model (courses are regularly run by Farmax).

5.4 Fonterra/AIM

The Fonterra 'method' is based on the Agricultural Inventory Model (AIM) developed by the Ministry for Primary Industries. AIM works at a 'national average' scale, and the method uses adjustments to allow AIM to run using farm level information.

The method only covers dairy farming.

5.4.1 Inputs

The main inputs are:

- Daily milk production
- Aggregate information on cow numbers, supplement and nitrogen fertiliser input with and without inhibitors, sourced from annual Farm Dairy records.

5.4.2 Outputs

The outputs are presented in a report to the farmer, showing:

- A summary of the input data
- CO_2 e/(effective) ha, split into CH_4 and N_2O, and the sources of each gas.
- The farm emissions relative to a benchmark group.
- The emissions intensity (kg CO_2 e/kgMS).

The method is proprietary, operated by Fonterra for shareholders.

5.5 Horticulture NZ

This model is a simple Excel spreadsheet, developed by MPI. Inasmuch as the sole biological greenhouse gas emissions from horticultural properties is nitrous oxide, the model calculates N_2O emissions relative to nitrogen fertiliser inputs.

The spreadsheet can also calculate CO_2 emissions from lime and dolomite applications.

5.5.1 Inputs

The sole input is the total tonnes of N fertiliser, by type of fertiliser:

(Non-urea N fertiliser, urea nitrogen coated with a urease inhibitor, urea fertiliser not coated with a urease inhibitor).

5.5.2 Outputs

Output is total tonnes CO_2 e.

The spreadsheet is available from MPI on request.

5.6 Ministry for the Environment (MfE)

This is an Excel spreadsheet with a number of worksheets which calculate CO_2 emissions from mainly energy use. It also has an agricultural worksheet which encompasses both carbon sequestration from forestry and CO_2, CH_4, N_2O emissions (as CO_2 e) from pastoral agriculture systems.

5.6.1 Inputs

Key inputs are:

- Planted/natural forest area (ha).
- Aggregate/average stock numbers (head) by stock type (dairy, non-dairy, sheep, deer), with the same numbers entered into 3 categories;
  - Enteric fermentation.
  - Manure management.
  - Agricultural soils.
- Total kg nitrogen fertiliser by fertiliser type (as outlined in Section 5.6.1).
- Total kg lime/dolomite applied.

5.6.2 Outputs

The main outputs are total CO_2, CH_4, and N_2O, by source.

The spreadsheet is available on the MfE website.

5.7 OverseerFM®

OverseerFM® is a nutrient budgeting model, available online. It calculates nutrient inputs and outputs from a farm system, as well as greenhouse gas emissions. The model covers a range of farm systems: pastoral, horticultural, and arable.

It can also incorporate forestry blocks, which includes calculation of carbon sequestration.

5.7.1 Inputs

OverseerFM® requires detailed inputs; e.g.

- Soil type, climatic data, pasture type(s), drainage.
- Effluent management systems for dairy farms.
- Crop type, areas, yields.
- Stock numbers by type, age, liveweight, production parameters.
- Allocation of feed in relation to stock.
- Supplementary feed inputs by type, amount, and what animals they are fed to.
- Detailed information on fertiliser inputs: types, amounts, timing, blocks applied to.
- Irrigation management.

5.7.2 Outputs

Key outputs are:

- Nutrient balance for the farm/block, showing inputs and outputs for a range of nutrients, e.g. N, P.
- Greenhouse gas emissions: CO_2 e/ha broken down by CH_4, N_2O, CO_2, and the source of each of the gases. Total farm emissions (CO_2 e) broken down by CH_4, N_2O, CO_2.
- Carbon sequestration by forestry (cumulative over time and annual tonnes), based on current ETS requirements. Note that the offset value of this against the farm emissions is not automatically calculated.

OverseerFM® is commercially available on an annual subscription basis to advisors and farmers. Training is required to operate the model.

5.8 Pork Industry

The PigGasNZ Calculator (**P**ork **I**ndustry **G**reenhouse **Gas** Calculator) is being developed to provide pork producers and advisers with a tool to estimate carbon dioxide equivalent emissions within the boundary of the piggery enterprise.

The PigGasNZ model is intended to provide flexibility to input farm-specific data and production characteristics. While it closely follows the New Zealand methodology for estimating greenhouse gas emissions from piggeries, it will provide the capacity to fine-tune production activities and the resulting emissions at the individual piggery enterprise level.

The model was not available to be assessed directly as part of this exercise, but the documentation provided indicated it would meet the requirements to calculate biological GHG emissions.

5.9 Summary of model output detail for methane and nitrous oxide

A summary of the detail of output around CH_4 and N_2O from the models is:

Table 3: Model breakdown of Methane and Nitrous Oxide

	Methane			Nitrous Oxide			
	Enteric	Dung	Effluent	Dung	Effluent	N fertiliser	Crops
Alltech	✓	✓	✗	✓	✗	✓	✗
E2M	✓	✓	✗	✓	✗	✓	✗
Farmax	✓	✓	✓	✓	✓	✓	✗
Fonterra	✓	✓	✓	✓	✓	✓	✗
HortNZ	na	na	na	na	na	✓	na
MfE	✓	✓	✓	✓	✓	✓	✗
Overseer	✓	✓	✓	✓	✓	✓	✓

5.10 Emission Factors

All the models, with the exception of the Alltech model, use the emission factors from the National Inventory.

Alltech, as an international consultancy firm, noted that their model uses farm-specific emissions factors for methane developed using IPCC methodologies, and IPCC EF for some non-animal related factors such as managed soil N_2O emissions.

6.0 RESULTS

The model information given by the providers was assessed as discussed in Section 4.0, with the results collated relative to farm type.

6.1 Dairy Farms

6.1.1 Waikato Dairy

Collation of the results showed:

Table 4: Collation of Waikato Dairy Modelling Results

	Detail Score	% methane	kg/ha CH_4 (CO_2 e)	kg/ha N_2O (CO_2 e)	Total GHG kg/ha (CO_2 e)
Alltech	45%	77%	9,297	2,701	11,998
E2M	57%	83%	6,234	1,297	7,531
Farmax	73%	75%	8,420	2,749	11,169
Fonterra	43%	82%	7,962	1,780	9,742
MfE	30%	75%	6,838	2,325	9,163
Overseer	92%	78%	8,525	2,356	10,881

Note:

(i) Detail Score: this is as per the assessment sheet, which was largely designed to give an indication of the level of detail required relative to the minimum set of requirements for inputs and outputs and was used as the basis for classifying the models; a higher score indicates a detailed model, a lower score a more simplistic model (as outlined in Section 3.0). A higher score does not mean the model is 'better' than a model with a lower score, just that there is more detailed information required to input.

(ii) % Methane. The average methane to nitrous oxide emissions (as expressed as CO_2e) for New Zealand pastoral farms, is 78% CH_4, 22% N_2O. This is used as a 'rule of thumb', as a check to see if the model results were falling around this ratio.

(iii) GHG emissions. These are expressed as (a) kg CO_2 e, and (b) per **total** hectare. The models varied as to whether they reported effective or total area. For reporting purposes, emissions are shown across total area.

(iv) Milksolids production. This is not shown in the table above, but there was some variation in milksolids production between the models. Alltech and Farmax calculated an allowance of milk used to feed calves, whereas the other models simply input the amount of milksolids sold to the milk company. Fonterra use daily milk production split by protein and fat content.

6.1.2 *Canterbury Dairy*

Collation of the results showed:

Table 5: Collation of Canterbury Dairy Modelling Results

	Detail Score	% methane	kg/ha CH_4 (CO_2 e)	kg/ha N_2O (CO_2 e)	Total GHG kg/ha (CO_2 e)
Alltech	45%	78%	6,792	1,943	8,735
E2M	57%	83%	6,506	1,295	7,801
Farmax	73%	75%	6,066	2,067	8,133
Fonterra	43%	81%	6,768	1,625	8,393
MfE	30%	75%	5,259	1,713	6,972
Overseer	92%	78%	6,451	1,853	8,304

6.2 Sheep & Beef Farms

6.2.1 *Sheep and Beef - Dairy Grazers*

Collation of the results showed:

Table 6: Collation of the Sheep and Beef with Dairy Grazers Modelling Results

	Detail Score	% methane	kg/ha CH_4 (CO_2 e)	kg/ha N_2O (CO_2 e)	Total GHG kg/ha (CO_2 e)
Farmax	68%	80%	4,334	1,103	5,437
MfE	32%	80%	7,619	1,873	9,492
Overseer	97%	75%	3,488	1,180	4,668

6.2.2 *Sheep and Beef – South Island High Country*

Collation of the results showed:

Table 7: Collation of the South Island High Country Modelling Results

	Detail Score	% methane	kg/ha CH_4 (CO_2 e)	kg/ha N_2O (CO_2 e)	Total GHG kg/ha (CO_2 e)
Alltech	47%	60%	814	533	1,347
Farmax	68%	81%	1,029	242	1,271
MfE	32%	81%	1,497	349	1,846
Overseer	97%	78%	1,281	351	1,632

6.2.3 *Sheep and Beef – South Island Intensive*

Collation of the results showed:

Table 8: Collation of the Sheep and Beef South Island Intensive Modelling Results

	Detail Score	% methane	kg/ha CH_4 (CO_2 e)	kg/ha N_2O (CO_2 e)	Total GHG kg/ha (CO_2 e)
E2M	59%	82%	4,766	1,046	5,812
Farmax	68%	81%	4,924	1,191	6,115
MfE	32%	80%	3,908	967	4,876
Overseer	97%	78%	5,250	1,480	6,730

6.3 Horticulture

The Overseer, HortNZ and MfE models are all capable of estimating the emissions from horticultural crops.

6.3.1 Citrus

Collation of the results showed:

Table 9: Collation of the Citrus Modelling Results

	Detail Score	kg/ha N_2O (CO_2 e)
HortNZ	64%	152
MfE	55%	152

6.4 Arable

Collation of the results showed:

Table 10: Collation of the Arable Modelling Results

	Detail Score	Cropping emissions kg/ha N_2O (CO_2 e)	Total GHG/ha (CO_2 e)
MfE	32%	820	1,851
Overseer	91%	946	2,224

Note: The 'cropping emission' is the N_2O emissions related with cropping on the farm (i.e. directly related to nitrogen fertiliser use). The total GHG/ha includes the biological greenhouse gas emissions from stock (both N_2O and CH_4) which graze the pasture of the crop rotation.

6.5 Deer

Collation of the results showed:

Table 11: Collation of the Deer Modelling Results

	Detail Score	% Methane	kg/ha CH_4 (CO_2 e)	kg/ha N_2O (CO_2 e)	Total GHG/ha (CO_2 e)
Farmax	68%	79%	3,380	875	4,254
MfE	32%	79%	3,113	847	3,960
Overseer	97%	80%	6,736	1,667	8,403

7.0 DISCUSSION

7.1 Variation in GHG Output Figures between the models

As can be seen from the results Section (Section 6.0), there is some variation in total GHG emissions as calculated by the various models, and in some cases, this is quite significant. This variation is driven by differences within models and operator differences.

7.1.1 Within Model Factors

Farm level GHG emissions are driven by three key factors:

- Amount of drymatter (DM) eaten, or the DMI.
- Amount of protein in the diet (%N).
- Amount of nitrogen (N) fertiliser applied.

Of these, the main driver is the amount of drymatter eaten. This means drymatter intake is crucial, which in turn is driven by the percentage of feed utilisation and energy (ME) levels (and within this animal ME requirements and ME available from feed). Most of the models have in-built DMI/utilisation/ME values, and it would appear that they are not necessarily aligned between models.

Similarly, most have % N factors relating to forages, and again it would appear these are not necessarily aligned between models.

Currently there are different emission factors for the three different classifications of nitrogen fertiliser, and it was not possible to discern as to whether several of the models were disaggregating N fertilisers accordingly, or just using an average emission factor against total N applied.

The end result is that the differences between results of different models will vary depending on the assumptions around DMI, ME, and % N levels.

7.1.2 Operator Error

This is a recurring theme in operating any models which can be a significant factor where figures are entered wrong, or transposed, or assumptions made resulting in differences in inputs being entered into the model.

After analysing the results, it is apparent that there is considerable variation between tool providers. It was evident that there was some error/lack of clarification in the data provided by He Waka Eke Noa and error in data input into the model. The results were not manipulated, so errors still stand in the report and account for some reasoning behind the variation between results. These then directly affected the resultant GHG emission figure.

Example of these are:

- The relatively low emission figure for the Waikato Dairy farm, from E2M, is largely due to assumptions around feed allocation between the milking platform and the support block.

- The relatively high emission figures for the S&B farm with dairy grazers, from the MfE model, would appear to be due to a relatively simple assumption around averaging stock numbers run.
- The high emission figures calculated by Overseer for the deer model is largely due to data input errors.
- The variation in how milksolids production is handled within each model (discussed above under the Waikato Dairy results) would give some variation in calculation of GHG emissions.

Where a summary output of the model had been provided, it was also difficult to ascertain what assumptions lay behind them.

7.1.2.1 Transfer of data between Farmax and Overseer

Currently Farmax and Overseer are the most widely used models by consultants and farmers, given they are (a) detailed models; and (b) readily available. Farmax is usually used for farm system modelling, and Overseer for nutrient budgeting, especially nitrogen leaching, and GHG estimation. Often, they are used in conjunction with each other, with information from one needing to be manually transferred to the other. An electronic means of transfer would significantly reduce operator transfer errors as noted above.

7.2 Farm Location

While this was recommended, some models currently do not allow for this. While necessary, the current lack of a farm location system (e.g. physical address/GPS coordinates) did not detract from the ability of the model to calculate GHG emissions but is something that needs to be standardised across models.

7.3 Context around Emission Figures Calculated

None of the models provided a contextual aspect to the resultant emission figures calculated, although the Alltech report does provide a page of discussion on factors which affect GHG emissions. Whether this is a component of the model itself, or a subsequent aspect of the report provided is unknown.

While the recommendations request a *Context for greenhouse gas emissions in terms of the He Waka Eke Noa Primary Sector Climate Change Partnership* as part of the presentation of the information to farmers, it is felt that this is something beyond the scope of the model itself.

The purpose of the model is to calculate the relevant biological GHG emissions for the farm. Given the complexity of responding to this in terms of mitigations/farm system change/offsetting, it is felt that this is beyond the scope of the model per se and falls within the realm of the advisor to take the figures generated and then provide suitable advice as to the measures the farmer may need to take.

7.4 Carbon Sequestration via Forestry

Currently some models incorporate a forestry sequestration component based on the current ETS requirements: Overseer, MfE and (to a degree) Alltech[5]. Farmax can incorporate forestry and has a sequestration component due for release shortly.

The models which currently calculate carbon sequestration levels, and align with the ETS, do not automatically offset this against the farm emissions.

7.5 Classification of the Models

The review would classify the models, as to their parameters (discussed in Section 3.0), as:

Table 12: Model Classification

	Simple	Intermediate	Detailed
Alltech		✓	
E2M		✓	
Farmax			✓
Fonterra		✓	
Hort NZ	✓		
MfE	✓		
Overseer			✓

The coverage of the models by farm type are:

Table 13: Model Coverage by Farm Type

	Dairy	Sheep & Beef	Deer	Horticulture	Arable
Alltech	✓	✓			
E2M	✓	✓			
Farmax	✓	✓	✓		
Fonterra	✓				
Hort NZ				✓	
MfE	✓	✓	✓	✓	✓
Overseer	✓	✓	✓	✓	✓

Note the Alltech model differentiates sheep & beef into sheep, beef, and then incorporates the GHG figures for the farm in the sequestration report.

There is an issue with the lack of model coverage over the 'miscellaneous' livestock types:

- Dairy Goats (included within Overseer)
- Meat Goats
- Milking sheep
- Alpacas

[5] The Alltech report shows carbon sequestration by: woodland, wetland, grassland, trees, hedgerow. Of these, only woodland is likely to be compatible with the NZ ETS requirements.

[It is understood that a recent upgrade of the MfE calculator includes a generic goat function as well as a function for alpacas].

While these are relatively small in number, there is an established dairy goat industry, as there also is for milking sheep, which is currently in an expansive mode. They are also prevalent on many of the smaller farming blocks, and while a simple GHG model may well suffice for these blocks, it still needs to cover the relevant livestock.

7.6 Minimum Standards

A summary of the models' performance relative to the draft minimum specifications is:

Table 14: Model Output Summary

Emissions source	Enteric Methane (CH_4)	Effluent Storage and dung deposited onto land (CH_4)	Total Methane from livestock	Effluent Storage (not effluent applied to land) (N_2O)	Agriculture Soils (N_2O)			Total Nitrous Oxide Emissions from livestock and fertilizers	CO_2 from application of Urea fertiliser to soil (if included in tool)
					Simple Tools (single value encompassing direct & indirect)	Intermediate & Detailed tools: separates direct from Indirect (leaching)	Intermediate and Detailed tools: separates direct from Indirect (volatilisation)		
Alltech	✓	✓	✓	✗	NA	✓	NA	✓	✓
E2M	✓	✓	✓	✗	NA	✓	NA	✓	✗
Farmax	✓	✓	✓	✗	NA	NA	✓	✓	✓
Fonterra/AIM	✓	✓	✓	✓	NA	✓	NA	✓	✗
Horticulture NZ	NA	NA	NA	NA	✓	NA	NA	✓	✓
Ministry for the Environment	✓	✓	✓	✓	✓	NA	NA	✓	✓
Overseer	✓	✓	✓	✓	NA	NA	✓	✓	✓

Table 15: Model performance relative to He Waka Eke Noa minimum standards

	Draft Minimum Specs for Methods				Presentation (area, address, system, context)					
	Valid emission factors (referenced)	Minimum inputs (livestock/fertiliser)	Model Structure/ equations	NZ Peer reviewed research for mitigation or sequestration	Reporting of GHG -metrics used	Area	Address or unique identification number	Farm system	HWEN context & sequestration statement	Tag if mitigations used are not in the NZI
Alltech	✓	✓	NIS	NIP	✗	✓	✓	✓	✗	✓
E2M	✓	✓	NIS	NIP	✗	✗	✗	✗	✗	NA
Farmax	✓	✓	NIS	NIP	✓	✓	✗	✓	✗	NA
Fonterra/AIM	✓	✓	NIS	NIP	✓	✓	✗	✓	✓	NA
Horticulture NZ	✓	✓	NIS	NIP	✓	✓	✓	✓	✓	NA
Ministry for the Environment	✓	✓	NIS	NIP	✗	✗	✗	✗	✗	NA
Overseer	✓	✓	NIS	✓	✓	✓	✓	✓	✗	NA

Key: ✓ = meets specification or recommendation ✗ = does not meet specification or recommendation NIP = No information provided NIS = Not in scope NA = not applicable

Based on the data supplied, all of the models appear to adequately calculate farm-level GHG emissions.

In noting this, not all models met the recommendations on presentation of results:

(i) Alltech, E2M, Farmax, did not explicitly show emissions for effluent storage and/or CO_2 from urea applications. It is possible some may allow for these factors (e.g. Farmax has an allowance for anaerobic lagoons built within it) but don't explicitly show it.

(ii) E2M and MfE models did not include the farm area.

(iii) E2M, Farmax, MfE models did not include a farm address or unique farm identifier.

(iv) The Fonterra/AIM method and HortNZ model were the only providers to include context around He Waka Eke Noa.

[Some further comments at an individual model level are provided in Appendix 3]

8.0 APPENDICES

8.1 Appendix 1: Pastoral Model Assessment Criteria for Model Detail

He Waka Eke Noa GHG Model Evaluation

Pastoral farms

Model:				
Farm/Farm Type:				
	Yes	No		
Physical Address of Farm				**Score**
			Include any specific comments alongside	Yes = 1
	Total	Effective		No = 0
Does the model work on total or effective area of the farm				
Livestock Details	Yes	No		
Does the model identify stock type				Score 0 through to 3
	No	Some break-down	Annual stock reconciliation	Monthly stock reconciliation
Does the model identify stock classes and numbers				
Production Parameters	Yes	No	Alternative: Uses average livestock liveweights	
Initial liveweight of animals				
	Yes	No		
Final/mature liveweights				
	Yes	No		
Liveweight gain or final carcass weights				
	Yes	No		
Milksolids production				
	Yes	No		
Lambing/Calving/Fawning %'s				

Diet

	Yes	No		Yes	No
Does the model indicate type of pasture grown			Does it provide an estimate of amount grown/consumed		
Does the model indicate ME values of forage within it					
Does the model indicate protein/N values of forage within it					
Type and amount of bought-in supplement identified			Does it show to which stock classes the supplement is fed		
Type/area/yield of crops grown identified			Does it show to which stock classes the crop is fed		

	No	Partial	Full description	
Types of nitrogen fertiliser applied to pasture identified (all N fertiliser, not just synthetic)				Score 0 through to 2

	Yes	No
Timing and rate of application to pasture identified		

	No	Partial	Full description	
Types of nitrogen fertiliser applied to crops identified				Score 0 through to 2

	Yes	No
Timing and rate of application to crops identified		

Model Output

	Yes	No		Amount of CH_4
Does the model provide an estimate of biogenic methane			[in either Tonnes or kg/ha CO_2e]	

Breakdown of methane:

	Yes	No
Enteric		
Dung		
Effluent		

	Yes	No		Amount of N_2O
Does the model provide an estimate of nitrous oxide			[in either Tonnes or kg/ha CO_2e]	

Breakdown of nitrous oxide

	Yes	No	
Excreta paddock			
Excreta effluent			[excluded for the S&B + dairy grazers scenario]
N fertiliser			
Crops			

	Yes	No
Is the methane:nitrous oxide ratio in the order of 78:22		

Other

	Yes	No
Does the model calculate forestry sequestration		

	Yes	No	Comment on the context:
Does the model provide context around the GHG emissions			

	Yes	No
Does the model include carbon dioxide in the outputs?		

Model classification	Simple	Intermediate	Detailed

Comments

Check List:

Soil data

Climate data

Manure management

Does the model include mitigation options/are these recognised

Is the model suitable for modelling GHG mitigations/system change

Ease of use

Other

Total Score	0	Out of 37

8.2 Appendix 2: Horticultural Model Assessment Criteria for Model Detail

Horticultural farms

Model:	
Farm/Farm Type:	

	Yes	No
Physical Address of Farm		

Include any specific comments alongside

	Total	Effective
Does the model work on total or effective area of the farm		

	Yes	No
Does the model specify the type of nitrogen fertiliser used		

	Yes	No
Does the model specify application rates (kg/ha, tonnes)		

	Yes	No	EF
Does the model use the average N emission factor			5.72

or EF's by fertiliser type:	Yes	No	
Non-urea nitrogen fertiliser			5.40
Urea nitrogen fertiliser not coated with urease inhibitor			5.07
Urea nitrogen fertiliser coated with urease inhibitor			4.86

Model output

	Yes	No	Amount of N_2O	
Does the model provide an estimate of nitrous oxide				[in either Tonnes or kg/ha CO_2e]

Other

Does the model give a breakdown of:	Yes	No	
Crop type(s) by area			Not included in total score below
Crop yields			
Cultivation methods			

	Simple	Intermediate	Detailed
Model classification			

Comments

Check List:
Is the model suitable for modelling GHG mitigations/system change
Ease of use
Other

Total Score	0	Out of 8

8.3 Appendix 3: Arable Model Assessment Criteria for Model Detail

Arable farms

Model:					**Score**
Farm/Farm Type:	Arable				Yes = 1
	Yes	No			No = 0
Physical Address of Farm					
			Include any specific comments alongside		
	Total	Effective			
Does the model work on total or effective area of the farm					
Livestock Details	Yes	No			
Does the model identify stock type					
	No	Some break-down	Annual stock reconciliation	Monthly stock reconciliation	
Does the model identify stock classes and numbers					Score 0 through to 3
Production Parameters					
Initial liveweight of animals	Yes	No	Alternative: Uses average livestock liveweights		
Final/mature liveweights	Yes	No			
Liveweight gain or final carcass weights	Yes	No			

Milksolids production — Yes / No

Lambing/Calving/Fawning %'s — Yes / No

Diet

Does the model indicate type of pasture grown — Yes / No

Does it provide an estimate of amount grown/consumed — Yes / No

Does the model indicate ME values of forage within it — Yes / No

Does the model indicate protein/N values of forage within it — Yes / No

Type and amount of bought-in supplement identified — Yes / No

Does it show to which stock classes the supplement is fed — Yes / No

Type/area/yield of crops grown identified — Yes / No

Does it show to which stock classes the crop is fed — Yes / No

Nitrogen fertiliser

Types of nitrogen fertiliser applied to pasture identified — No / Partial / Full description

(all N fertiliser, not just synthetic)				Score 0 through to 2

Timing and rate of application to pasture identified

Yes	No

Types of nitrogen fertiliser applied to crops identified

No	Partial	Full description	
			Score 0 through to 2

Timing and rate of application to crops identified

Yes	No

	Yes	No	EF
Does the model use the average N emission factor			5.72

or EF's by fertiliser type:	Yes	No	
Non-urea nitrogen fertiliser			5.40
Urea nitrogen fertiliser not coated with urease inhibitor			5.07
Urea nitrogen fertiliser coated with urease inhibitor			4.86

Model Output

	Yes	No		Amount of CH_4
Does the model provide an estimate of biogenic methane			[in either Tonnes or kg/ha CO_2e]	

Breakdown of methane:	Yes	No
Enteric		
Dung		

Effluent		

Does the model provide an estimate of nitrous oxide

Yes	No		Amount of N_2O
		[in either Tonnes or kg/ha CO_2e]	

Breakdown of nitrous oxide	Yes	No
Excreta paddock		
Excreta effluent		
N fertiliser		
Crops		

total

Other

	Yes	No
Does the model calculate forestry sequestration		

	Yes	No
Does the model provide context around the GHG emissions		

Comment on the context:

	Yes	No
Does the model include carbon dioxide in the outputs?		

Does the model give a breakdown of:	Yes	No
Crop type(s) by area		
Crop yields		
Cultivation methods		

Model classification

Simple	Intermediate	Detailed

Comments

Check List:

Soil data

Climate data

Manure management

Does the model include mitigation options/are these recognised

Is the model suitable for modelling GHG mitigations/system change

Ease of use

Other

Total Score [ ] out of 39

8.4 Appendix 4: Individual Model Comments

The following are some comments relating to the individual models.

Alltech

- Reports provided displayed results as emission intensity (CO_2 e/kgMS or kg LW) – He Waka Eke Noa recommends presentation is to display as absolute emissions.
- Some sheep & beef farm figures were compared with Alltech averages – it is unclear how these apply in a New Zealand context.
- Sheep & beef farm comprised three reports: sheep, beef, sequestration (which collated results from the first two). To be farmer friendly, it may be best to have a single report.
- Sequestration report included sequestration by items not included in the ETS/NZ inventory. He Waka Eke Noa recommended presentation is to clarify this through a disclaimer under the requirements. Furthermore, the methodology for this sequestration should be referenced.

E2M

- Linear programme-based model – would restrict use to qualified operators, although proprietary model anyhow.
- Output sheet very basic – gives limited indication of inputs used. Needs to clarify GHG emissions as discussed in the recommendations.
- LP base does mean it is very useful in optimisation modelling.

Farmax

- Detailed farm system model.
- Weakness in GHG area – no information on cropping (N) fertiliser, no information on effluent management in dairy model, although there are generic assumptions made for 'anaerobic lagoons' within the model.

Fonterra

- Good presentation of output re biological GHG emissions and source, and summary of farm parameters.
- Limited information on how the method works (within the GHG report provided), but supporting reports provided.

HortNZ

- Basic spreadsheet model, for calculating nitrous oxide emissions from nitrogen fertilisers only.
- If an orchard were also running animals – would need to use an alternative model.

MfE

- Basic spreadsheet model

- Inasmuch as the main inputs are average stock numbers, it needs to provide guidance as to how numbers should be calculated, especially for sheep & beef farms, and especially for farms trading stock.
- Output display very limited – only shows total GHGs by type. No indication of the area of the farm.

Overseer

- Covers all types of farm systems.
- Good detail on nitrogen fertilisers used.
- Summary of total GHG emissions on front window includes CO2 emissions – have to refer to different window to discern biological emissions.
- Has additional feature that allows for nutrient losses to be modelled from the farming system.

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