Initial review of the suitability of OVERSEER Nutrient Budgets Model for farm scale greenhouse gas reporting

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This report has been prepared for the Ministry for Primary Industries (MPI) on behalf of the Biological Emissions Reference Group (BERG), and is confidential to the members of BERG and AgResearch Ltd. No part of this report may be copied, used, modified or disclosed by any means without their consent.

BERG is a partnership between New Zealand's agricultural sector and the Government. BERG has been tasked with collaboratively establishing a robust and agreed evidence base on opportunities available, now and in future, to reduce biological greenhouse gas emissions (methane and nitrous oxide) on-farm. In doing so, it will consider the costs, benefits, and barriers.

This report is one of several commissioned by BERG to build this initial evidence base to inform future policy development. If a policy process were to commence following this analysis, further work would be required. BERG welcomes this report and supports the analysis contained within it. However, it is out-of-scope of the BERG's Terms of Reference to express a preference for any specific options identified or recommended by the author(s).

BERG is comprised of the following voting members: Beef + Lamb New Zealand, DairyNZ Limited, Deer Industry New Zealand, Federated Farmers of New Zealand, The Fertiliser Association of New Zealand, Fonterra, Horticulture New Zealand, Ministry for Primary Industries, and Ministry for the Environment.

The following organisations are observers of BERG: Climate Change Iwi Leaders Group, Meat Industry Association of New Zealand, Ministry of Business, Innovation and Employment, Ministry of Foreign Affairs & Trade, and The Treasury.

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1. Executive Summary

Under the new Paris Agreement on Climate Change, New Zealand's Nationally Determined Contribution (NDC), for the 2021-2030 period is to reduce greenhouse gas (GHG) emissions to 30% below 2005 levels (equivalent to 11% below 1990 levels) by 2030. As our land resources are our largest sources and sinks of GHG emissions, the Paris Agreement creates significant challenges and opportunities for our primary industries. The Biological Emissions Reference Group (BERG), comprised of government and industry members, has therefore been established to collaboratively build a robust and agreed evidence base on what the agricultural sector can do on-farm to reduce emissions.

To help policy developers understand the potential role of OVERSEER® Nutrient Budgets (OVERSEER®) in meeting the national GHG commitments, more information is needed on how well the model is aligned to national inventory methods and what is required to ensure on-going confidence in it being representative of farm-scale GHG losses. BERG therefore commissioned this report to provide an initial assessment of the suitability of OVERSEER® for on-farm GHG reporting, and its alignment to New Zealand's Agricultural GHG Inventory model (NZAgInv), while recognising the two models operate at different spatial scales (farm vs national scale, respectively). The report addresses three key issues:

- An assessment of the confidence in OVERSEER® for GHG reporting. Although the report focusses on the technical aspects of OVERSEER®, it also addresses some issues on documentation, QA/QC and processes for making changes.
- Recommendations on a process for ongoing calibration of the GHG outputs across a range of typical farm systems.
- Recommendations for options for systems and processes for incorporating changes and updates to OVERSEER® and New Zealand's Agricultural GHG Inventory (NZAgInv) to ensure on-going alignment and consistency.

The report is not intended to assess the suitability of OVERSEER® as a regulatory tool for agricultural GHG emissions.

Our assessment focusses on the main source of biological greenhouse gas emissions: enteric methane (CH_4) and nitrous oxide (N_2O) from dairy, sheep, beef and deer livestock systems, which contribute over 90% of the total agricultural CH_4 and N_2O emissions in

New Zealand. The case-studies that were available, and the component of OVERSEER® assessed in each case-study were:

Case-study	OVERSEER® component assessed
Dairy cow (Kelliher et al. 2015)	Metabolisable energy (ME) requirements
Pastoral farms on moderately well drained soils: • Dairy farms in Waikato, Taranaki, Canterbury and Southland • Sheep & Beef farms in King Country, Taranaki, Waiaroa, Canterbury and West Otago • Deer farms in Hawkes Bay and Southland	N_2O emissions
Irrigated dairy farm on contrasting soils	N_2O emissions

Assessment of confidence

Enteric CH_4 emissions are driven by metabolisable energy (ME) and dry matter intake (DMI) requirements of livestock. Kelliher et al. (2015) compared estimates of the ME and DMI requirements for a dairy cow using either OVERSEER® or the New Zealand's Agricultural GHG Inventory model (NZAgInv). This showed that the estimates from OVERSEER® were 14% higher than those from NZAgInv. In this report we further investigated the reasons for the difference and re-ran the analysis from Kelliher et al. (2015) using the updated version of OVERSEER®. This showed that the OVERSEER® estimate for ME requirement was 10% higher, largely due to the estimate of the ME requirement for animal movement associated with walking during grazing (MEmove). On further investigation, it was revealed that there was an error in the MEmove equation in OVERSEER®. After the error was corrected in the OVERSEER® development version, the estimated total ME requirements using OVERSEER® and NZAgInv were very similar.

However, there were differences between the individual components of the estimated total ME requirements. Investigating the reasons for these differences was beyond the scope of this project, but they could be due to differences in the choice and implementation of equations between OVERSEER® and NZAgInv. The rationale behind the choice of equations and parameters for estimating ME requirements in OVERSEER®, and their implementation, has been independently reviewed by Pacheco et al. (2016). We strongly endorse their recommendation for more transparency and documentation on the choice of the ME equations and parameters in OVERSEER®, and their implementation.

To assess the suitability of OVERSEER® for estimating on-farm N_2O emissions a range of existing files for dairy, sheep and beef, and deer systems were used to back-calculate the implied N_2O emission factors (EFs) for urine patches. OVERSEER® allows three options for the choice of EFs, with 2. being the option used in NZAgInv:

1. Farm-specific (default setting in OVERSEER®)
2. Annual average EFs (with default EFs values largely the same as in NZAgInv)
3. Annual average EFs, seasonally adjusted (this proportions emissions across months based on soil moisture content)

For this analysis we used a software tool, specifically developed for this project, to extract the required data from the files for analysis. The results showed that when selecting the N_2O EF option 'annual EFs' or 'annual EFs, seasonally adjusted', the implied EFs ranged from 0.0008 to 0.0242 kg N_2O-N/kg urine N for dairy, and from 0.0002 to 0.026 for sheep, beef and deer. These results were consistent with the range of results from New Zealand field trials that underpin the EF for urine patches in the NZAgInv (a mean value of 0.01).

When selecting 'farm-specific' EFs, OVERSEER® adjusts the EFs based on temperature and soil water content. Using this setting, the back-calculated implied EFs were generally within the range 0.0006 to 0.0238 kg N_2O-N/kg urine N. However, for some of the farms the implied EFs were 12-14 times greater than the range of results from New Zealand field trials. These exceptionally high EFs are most likely due to the assumed relationship in OVERSEER® between EF and the soil water content. Our analysis also showed that, when the 'farm-specific emission factors' option was selected, the implied EFs for urine, dung and fertiliser were all the same. This is inconsistent with NZAgInv where different values are used for EFs associated with urine (0.01 kg N_2O-N/kg urine N), dung (0.0025 kg N_2O-N/kg dung N), and N fertiliser (0.0059 kg N_2O-N/kg N fertiliser).
Based on these results we recommend that i) 'Annual average EFs' are set as the default option in OVERSEER® and the EFs are the same as those in NZAgInv, and ii) 'Farm-specific EFs' and 'annual average EFs, seasonally adjusted' are disabled until the equations underpinning these options are carefully reviewed, and experts are satisfied that currently available spatial and/or temporal information is robust enough to justify their use.

Biological GHG emissions associated with non-livestock agricultural systems are largely driven by N fertiliser use and thus by the N_2O EF associated with the N fertiliser. As the majority of studies on the N_2O EF for N fertiliser are conducted for urea applied to pastoral land, it is recommended that a review is commissioned on N_2O emissions from urea and non-urea fertilisers to determine appropriate values for the complete range of New Zealand agricultural systems.

Process for ongoing calibration

The suitability of OVERSEER® for on-farm GHG reporting, and its alignment to NZAgInv, depends on calculations using the best available information. Consequently, OVERSEER® needs to be updated when better information becomes available. We recommend the compilation and use of input data sets for the purpose of calibration. Calibration of the GHG outputs across a range of farming systems can be closely aligned to the process for evaluation and re-calibration of the N leaching model in OVERSEER® as suggested by Shepherd et al. (2015). In particular, an evaluation of the effects of OVERSEER® updates on the calculated DMI, N intake and N excretion rates is critical, as these are key parameters for determining the enteric CH_4 and soil N_2O emissions.

Ongoing evaluation and updates of the CH_4 emission factors and the 'annual average' N_2O emission factors should be aligned with changes of these parameters in NZAgInv. The methods used for the proportioning the 'annual average' N_2O emissions across the months and for estimating 'farm-specific' N_2O emissions based on soil moisture content and temperature will require ongoing evaluation and calibration against experimental data.

It is recommended that i) a process is defined to ensure reviews of relevant published research in these areas are conducted at regular intervals; and ii) a calibration data set is developed for validating the algorithms in OVERSEER® for estimating DMI, N intake and N excretion and for apportioning annual N_2O emissions across the months and for determining 'farm-specific' N_2O emissions.

Process for ongoing alignment between OVERSEER® and NZAgInv

OVERSEER Ltd and MPI's inventory team have separate established processes for evaluating and recommending changes to their models. In this report we have highlighted where alignment and information sharing could occur within these established processes. We recommend that OVERSEER Ltd and MPI's Inventory team discuss the proposed options for ensuring ongoing alignment and that the agreed approach is formally implemented.

Conclusion

Overall our assessment is that the OVERSEER® structure is suitable for farm-scale GHG reporting. Its general approaches and principles of calculating ME requirements, DMI and N excretion are supported by current understanding. Moreover, OVERSEER® can account for different farming systems and management practices. [1]

However, on-farm GHG reporting is reliant on full confidence in the GHG estimates using OVERSEER® and the current project was constrained by lack of full access to the OVERSEER® code. As a result of our project, discussions are being held with OVERSEER Ltd to provide a small working group (including modellers/ programmers and animal, soil and system scientists) permission to scrutinise the code, and to make recommendations for any required changes. This independent process will provide confidence to OVERSEER® users that the choice and implementation of the equations for calculating CH_4 and N_2O emissions are fully understood and justified.

Our key recommendations are that:

- Following the initial agreement from OVERSEER Ltd to provide full access to the code, a small working group is commissioned to undertake a full assessment of all ME, DMI and GHG equations and their implementation in OVERSEER®.
- The equations and their implementation in OVERSEER® are evaluated for all New Zealand farming systems including dairying, sheep, beef, deer, horticulture and arable.
- 'Annual average EFs' are set as the default option for calculating N_2O emissions in OVERSEER® and all EFs are the same as those in NZAgInv.
- 'Farm-specific' and 'annual average, seasonally adjusted' EFs are disabled until the methods underpinning these options are carefully reviewed, and experts are satisfied that currently available spatial and/or temporal information is robust enough to justify their use.
- The rationale behind choice of equations and parameters for estimating ME, DMI and GHG emissions is fully documented in technical manuals.

[1]This report does not comment or make recommendations on whether it is appropriate to use OVERSEER® on different farm systems, as this would be a policy decision taking into account many practical considerations. For farmers and farm consultants who are already using the model to calculate nutrient budgets, as is currently the case for dairy farms and as required in some regional council jurisdictions, OVERSEER® has the added advantage that the GHG emissions can be determined without any additional work.

- A calibration data set is developed for validating the algorithms in OVERSEER® for estimating DMI, N intake and N excretion, for apportioning annual N_2O emissions across the months, and for determining N_2O emissions based on soil moisture and temperature.
- OVERSEER Ltd and MPI's Inventory team discuss the proposed options for ensuring ongoing alignment between OVERSEER® and NZAgInv, and that the agreed approach is formally implemented.

Other, more detailed, recommendations are that:

- Updates on EFs and fractions as identified in our short report from January (see Appendix) are made as soon as practical.
- If 'farm-specific EFs' are accepted by experts, methods for decoupling $EF_{3\ URINE}$, $EF_{3\ DUNG}$, EF_1 and $EF_{1\ UREA}$ need to be included.
- A review is commissioned on N_2O from urea and non-urea fertilisers to determine appropriate values for a wide range of New Zealand agricultural systems.
- A process is established to ensure reviews of relevant published research are conducted at regular intervals and the potential implications for OVERSEER® are determined.

2. Glossary

BERG, the Biological Emissions Reference Group

CH_4, methane

DM, dry matter

DMI, dry matter intake

EFs, emission factors (e.g. g CH_4 emitted per kg DMI; or kg N_2O-N per kg N)

$EF_{3\ URINE}$, emission factor or animal urine deposited during grazing

$EF_{3\ DUNG}$, emission factor or animal dung deposited during grazing

$EF_{1\ UREA}$, emission factor for urea fertilisers

EF_1, emission factor for other N fertilisers and effluent applied to land

GHG, greenhouse gas

ME, metabolisable energy

MEgraze, metabolisable energy requirements for grazing animals in addition to ME required by similar animals that are housed. In OVERSEER®, MEgraze is divided in MEmove, MEchew and MEactivity

MEmove, ME requirements for animal movement associated with walking during grazing

MEchew, ME requirements for chewing

MEactivity, ME requirements for general activity associated with finding water and shelter and, for dairy cows, walking to the farm dairy

N_2O, nitrous oxide

NZAgInv, New Zealand's Agricultural GHG Inventory

OVERSEER®, OVERSEER® Nutrient Budgets, a software application supporting farmers and growers to make informed decisions about their nutrient use on-farm

3. Background

New Zealand signed (and later ratified) a new post-2020 global climate change agreement in December 2015 in Paris, at the twenty-first session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC). New Zealand's Nationally Determined Contribution (NDC), or target, for the 2021-2030 period is to reduce greenhouse gas (GHG) emissions to 30% below 2005 levels (equivalent to 11% below 1990 levels) by 2030. New Zealand's target applies to the whole of the economy, so all sectors will need to explore ways to reduce emissions. However, as our land resources are our largest sources and sinks of GHG emissions, the Paris Agreement creates significant challenges and opportunities for our primary industries.

As a result, the Biological Emissions Reference Group (BERG), comprised of government and industry members, has been established to collaboratively build a robust and agreed evidence base on what the agricultural sector can do on-farm to reduce emissions, now and in the future, and assess the costs and opportunities of doing so.

OVERSEER® Nutrient Budgets (OVERSEER®) provides a method for understanding nutrient cycling, including greenhouse gas emissions, at farm scale. To help policy developers understand its potential role in meeting the national GHG commitments, more information is needed on: i) how well OVERSEER is aligned to national inventory methods, ii) what is required to ensure on-going confidence in it being representative of farm scale GHG losses, and iii) what systems are required to ensure it remains aligned with the national inventory while at the same time being current with changing farm practices and mitigations. BERG therefore commissioned this report to provide an initial assessment of the suitability of OVERSEER® for on-farm GHG reporting. The report is not intended to assess the suitability of OVERSEER® as a regulatory tool for agricultural GHG emissions.

New Zealand's dairy, sheep, beef and deer livestock systems contribute over 90% of the total biological emissions from agriculture. Biological GHG emissions associated with non-livestock agricultural systems are relatively minor and are largely driven by N fertiliser use. N_2O emissions associated with N fertiliser use are determined by the amount of N used (an input for OVERSEER®) and the N_2O EF for N fertiliser.

In this report we will focus on the main sources of biological greenhouse gas emissions: enteric methane (CH_4) and nitrous oxide (N_2O) from livestock systems. An assessment and recommendations on N_2O EFs for N fertiliser is also included.

Recently, Vibart & Selbie (2014) and Vibart et al. (2015) reviewed agricultural GHG tools and models to assess which was the most appropriate on-farm GHG accounting tool for New Zealand dairy farmers. These authors concluded that the OVERSEER® model was the 'tool of choice' based on criteria including capability to estimate enteric methane, nitrous oxide and carbon dioxide emissions at farm and monthly scales; account for grazing livestock; ease of use and availability, representative of New Zealand conditions; and ability to account for mitigation strategies. An added advantage of using OVERSEER® is that the GHG emissions can be assessed without any additional work by farmers and farm consultants who are already using the model. The farm data currently used to develop the OVERSEER® nutrient budgets can also be used to generate a GHG report.

This report provides an initial assessment of whether OVERSEER® is 'fit-for-purpose' as a reporting tool for on-farm biological GHG emissions. The report addresses three key issues:

- An assessment of the confidence in OVERSEER® for reporting of biological GHG emissions. Although the report focusses on the technical aspects of OVERSEER®, it also addresses some issues on documentation, QA/QC and processes for making changes.
- Recommendations on a process for ongoing calibration of the GHG outputs across a range of typical farm systems.
- Recommendations for options for systems and processes for incorporating changes and updates to OVERSEER® and New Zealand's Agricultural GHG Inventory (NZAgInv) to ensure on-going alignment and consistency.

The report then provides conclusions and an initial assessment of the suitability of OVERSEER® for on-farm GHG reporting.

The case-studies we used, and the component of OVERSEER® assessed in each case-study, were:

Case-study	***OVERSEER® assessment***
Dairy cow (Kelliher et al. 2015)	Metabolisable energy (ME) requirements
Pastoral farms on moderately well drained soils: • Dairy farms in Waikato, Taranaki, Canterbury and Southland • Sheep & Beef farms in King Country, Taranaki, Waiaroa, Canterbury and West Otago • Deer farms in Hawkes Bay and Southland	N_2O emissions
Irrigated dairy farm on contrasting soils	N_2O emissions

It should be noted that while OVERSEER® and NZAgInv operate at the same time scale (monthly calculations that are aggregated to annual outputs), the two models operate at different spatial scales (farm vs national scale, respectively) and, as a result, also use input data at a different scale: site-specific vs national average data. Moreover, while NZAgInv is used only to meet international GHG reporting requirements, OVERSEER is currently primarily used to calculate nutrient budgets, but on-farm GHG emission estimates are also available. For this review, we have assessed whether *the approaches* for estimating GHG emissions in the two models are consistent, i.e. that the assumptions and EFs are consistent, though recognising that some difference may occur to ensure the models each provide the best possible estimate of GHG emissions appropriate for the scale at which they are operating, and at which input data are required. The differences in scale mean that OVERSEER® and NZAgInv estimates will not always be exactly the same. For example, OVERSEER® estimates of N leaching should be locally appropriate, rather than being based on the national average fraction of N leaching used in NZAgInv.

It should also be noted that because of the different spatial scales and purposes of the models, there could be differences in the importance/priority of a certain farm practice or farming type. For example, urea is the most common N fertiliser used in NZ and thus for the NZAgInv it is most important to obtain an accurate N_2O EF for this fertiliser type, as other types have only a small effect on the estimated national emissions. However, for individual farmers that use N fertilisers other than urea, it is important that OVERSEER® uses the best possible EF for these alternative N fertilisers.

4. Assessment of confidence for GHG reporting

For all animal production systems, OVERSEER® (http://overseer.org.nz/) and NZAgInv (Ministry for Primary Industries, 2016) use the same basic principles for estimating enteric methane (CH_4) and nitrous oxide (N_2O) emissions agricultural systems (Figure 1). However, where NZAgInv is largely based on the Australian feeding standard algorithms (CSIRO 1990, 2007), OVERSEER® also uses algorithms from Nicol and Brookes (2007). However, it should be noted that the algorithms in Nicol and Brookes (2007) are largely based on the Australian feeding standard algorithms (CSIRO 1990, 2007).

The calculations use animal production (e.g. meat and milk) and population characteristics (e.g. live weight, age, breeding status) to estimate the metabolisable energy (ME) requirements of the animals. Then, using data on the ME content of the diet, the total amount of dry matter intake (DMI) is estimated. Using measured data on CH_4 emissions per unit of DMI (i.e. the CH_4 emission factor), total enteric CH_4 is estimated.

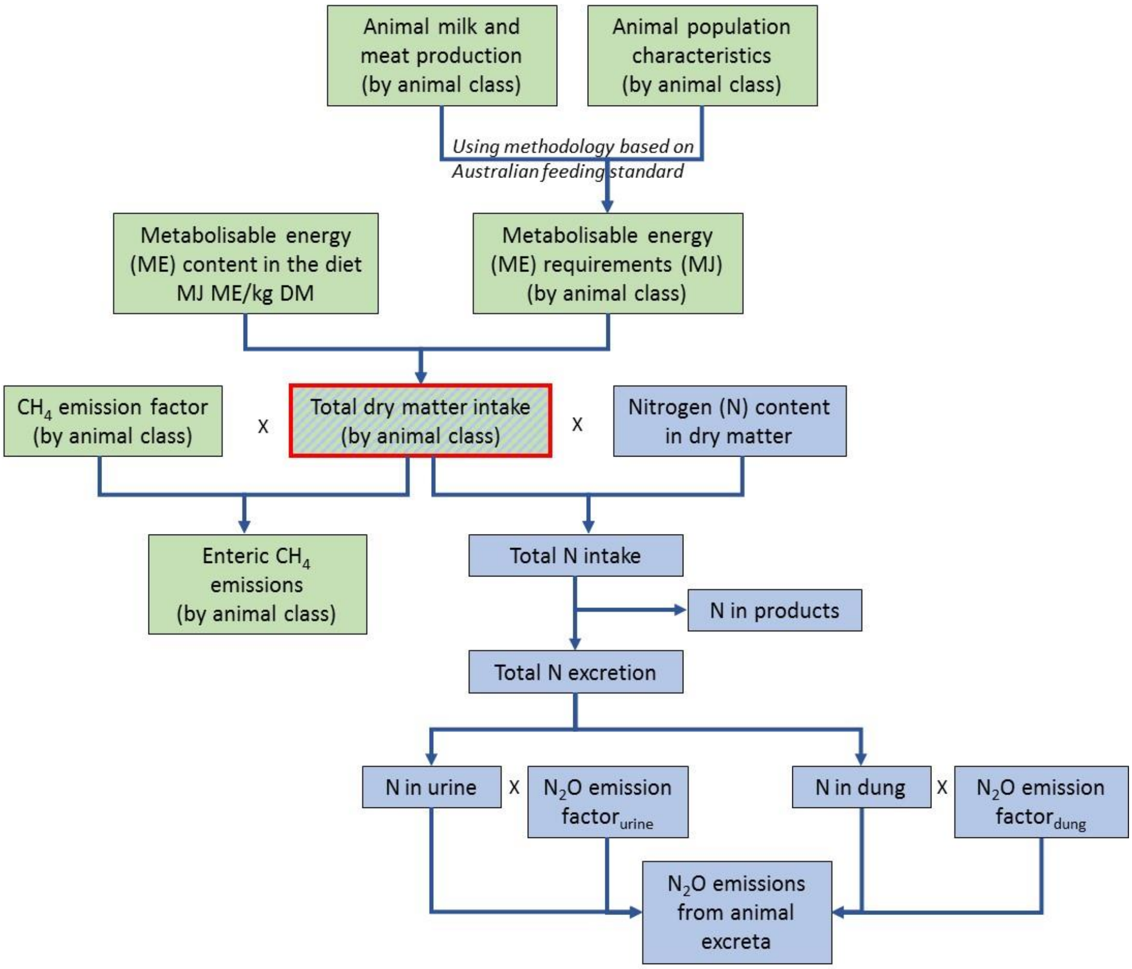


Figure 1: Schematic overview of the basic approach in NZAgInv and OVERSEER® for estimating methane (CH_4) and nitrous oxide (N_2O) emission for animal production systems. Green boxes refer to CH_4, blue boxes to N_2O. The red lined box (total dry matter intake) represents the main parameter that connects the CH_4 and N_2O calculations.

Dry matter intake is also the key input for estimating N_2O emissions from animal excreta (which represent 80-85% of the N_2O emissions). Using DMI and data on the N content of the diet, total N intake is estimated. Then, using production data, the amount of N exported in product is calculated and subtracted from N intake, to give total N excretion. Using IPCC default values or measured country-specific data on N_2O EFs for animal excreta, total N_2O is estimated. The accuracy of DMI estimates is therefore one of the key drivers of the suitability of a model for GHG reporting. As stated, DMI is determined by the ME requirements of the animals divided by the pasture (feed) ME content.

For non-livestock agricultural systems GHG emissions are largely driven by N fertiliser use. The N_2O emissions associated with N fertiliser use are determined by the amount of N used (an input parameter for OVERSEER®) and the N_2O EF for N fertiliser. Recommendations on the N_2O EFs for N fertilisers are discussed in section 3.1.2 and in the Appendix.

4.1 Methane

4.1.1 Approach

As an initial assessment of the suitability of OVERSEER® to estimate methane emissions, we further investigated the reasons behind a difference in the calculated total ME requirements reported by Kelliher et al. (2015) (as indicated in our short report to the Biological Emissions Reference Group in Jan 2017; see Appendix). For this project, we used the same input data which had been used by Kelliher et al. (2015), to calculate the components of the total ME requirement for the average dairy cow in New Zealand during the “inventory” year 2013 (i.e. January to December 2013), using both OVERSEER® and NZAgInv. Kelliher et al. (2015) used OVERSEER® version 6.2.0 for their calculations. However, OVERSEER® version 6.2.0 is no longer in use. Moreover, to extract the calculated components of the total ME requirement, we needed to use the current OVERSEER® ‘development’ version, as these outputs cannot be extracted from the publically available online version. However, we checked that the development version calculated the same total ME requirement as the online version of OVERSEER® (v 6.2.3), which was indeed the case. For NZAgInv, we used the same version which had been used by Kelliher et al. (2015) and code was written to output the calculated individual components of the total ME requirement.

4.1.2 Results

Comparison of animal feed intake estimates

By changing from OVERSEER® v 6.2.0 to v 6.2.3, the estimated annual DMI was found to have decreased by 5% due to updates to the algorithms in the later version. Although release notes on the changes are listed on the website, the technical description is not included and hence technical details on these changes are not available. The OVERSEER® v 6.2.3 estimate (4,610 kg DMI/cow/yr) was 10% larger than the NZAgInv estimate (4,200 kg DMI/cow/yr). Estimates of annual feed intake or total ME requirement of grazing animals will always carry uncertainty. Some of the calculations used by OVERSEER® were described by Nicol and Brookes (2007), who wrote "it is generally accepted that 'estimates' of nutrient requirements are only accurate to within plus or minus 10%". The calculations used by NZAgInv are known as the CSIRO feeding standard (CSIRO 2007). Using expert judgement, the estimated uncertainty of CSIRO feeding standard calculations was also ± 10% for 95% confidence (Kelliher et al. 2007). On this basis, the above difference between the OVERSEER® and NZAgInv estimates (4,610 and 4,200 kg DMI/cow/yr, respectively) is within the bounds of the uncertainty of the estimates of the two models. Nevertheless, as the algorithms of Nicol and Brookes (2007) are largely based on the CSIRO feeding standards, one could expect the estimates to closely align. Furthermore, a systematic 10% difference in estimates of the annual ME (feed) requirement (and any costs that may in future be associated with that) will be significant for farmers.

One of the recent updates to OVERSEER® was to provide monthly estimates of feed intake. For the mean dairy cow, the OVERSEER® estimates of monthly feed intake were compared to those determined by NZAgInv (Figure 2). The two sets of monthly DMI estimates followed similar patterns. However, for January – June, the OVERSEER® estimate was 20 - 50 kg (12% on average) larger. The comparison was more variable during July – December. For example, the OVERSEER® estimate was 161 kg (59%) greater in August and 64 kg (14%) less in October. For OVERSEER®, the calf was born on 20 July, while for NZAgInv, the calf was born on 1 August. Calf birth initiated lactation by the cow which increased the estimated feed intake. While both sets of calculations used the same input data for the season's milk production, the monthly increase in feed intake due to lactation depended on how OVERSEER® and NZAgInv estimated the monthly time courses of lactation. The comparisons of monthly feed intake from July onwards suggested that OVERSEER® and NZAgInv had different estimates of the monthly time course of lactation. However, the two models may also have different estimates for monthly weight gains and losses, which would also affect the monthly time course of DMI.

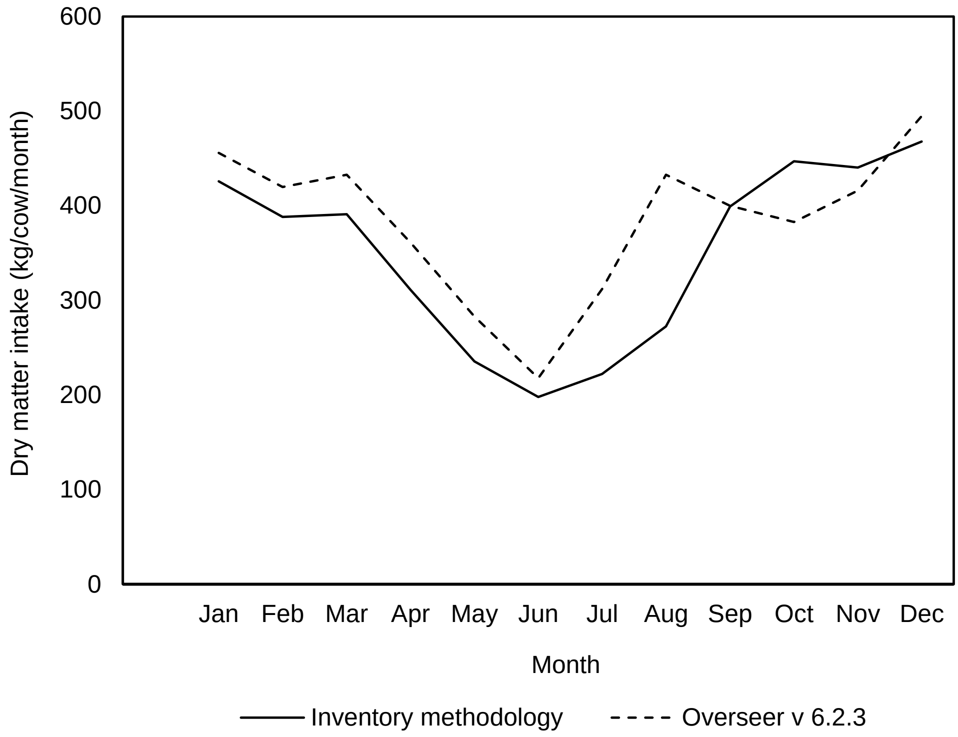


Figure 2. Monthly estimates of dairy cow dry matter intake (DMI) estimated by OVERSEER® v 6.2.3 and NZAgInv during the "inventory" year 2013.

Comparison of components of the total ME requirement estimates

The components of total ME requirement we compared were the ME requirements for basal metabolism, grazing, lactation, pregnancy, and weight gain. The sum of the ME requirement for lactation, pregnancy and weight gain was attributed to 'production' and the remainder to 'maintenance'. While Kelliher et al. (2015) thought OVERSEER® probably had estimated a larger ME requirement for maintenance than NZAgInv, they did not have access to the component estimates as they were not available at the time. For this project these estimates have been made available.

The estimated annual total ME requirement was 52,486 MJ for OVERSEER® and 47,830 MJ for NZAgInv (Table 1a). Consequently, like DMI, the OVERSEER® estimate for total ME requirement was 10% larger (4,656 MJ) than that of the NZAgInv. The two largest components were the ME requirements for lactation and basal metabolism which summed to 40,617 MJ for OVERSEER® and 39,769 MJ for NZAgInv. For these components combined, the OVERSEER® estimate was only 2% larger than that of the NZAgInv. In contrast, the OVERSEER® estimate of the ME requirement for grazing was 3,133 MJ (45%) larger than that of the NZAgInv.

In OVERSEER®, this 'MEgraze' component applies to all livestock classes and estimates the ME requirements for animal movement associated with walking during grazing (MEmove), for chewing (MEchew) and for general activity associated with finding water and shelter and, for dairy cows, walking to the farm dairy (MEactivity) (Wheeler, 2016). Further investigation of these calculations indicated that MEmove was much larger than MEchew and MEactivity. Consequently, MEmove was thought to account for most of the considerable difference between the OVERSEER® and NZAgInv estimates for *MEgraze*, as well as the 10% difference between the two estimates of *total ME* requirement.

Table 1a. Annual estimates of dairy cow metabolisable energy (ME) requirements using the development version of OVERSEER® and NZAgInv for the "inventory" year 2013. Values in brackets represent the % of total ME requirement. Values in square brackets represent the % difference of the OVERSEER® estimates compared with the NZAgInv estimates.

ME requirement	OVERSEER v 6.2.3 MJ ME/year	NZAgInv MJ ME/year	Difference MJ ME/year
Basal metabolism	16,756 (32%)	17,496 (37%)	-740 [-4%]
Grazing	6,910 (13%)	3,777 (8%)	3,133 [45%]
10% of Production[a]	1,863 (4%)	2,414 (5%)	-551 [-30%]
Lactation	23,681 (45%)	22,273 (46%)	1, 408 [6%]
Pregnancy	2,028 (4%)	1,870 (4%)	158 [8%]
Weight gain	1,248 (2%)	0 (0%)	1,248 [100%]
Total ME req	**52,486 (100%)**	**47,830 (100%)**	**4,656 [10%]**

[a] This factor accounts for the fact that maintenance energy requirements are not fixed, but increase with the level of productivity (CSIRO 1990). In NZAgInv, this represents 10% of the sum of the ME requirements for lactation and pregnancy. In OVERSEER®, it represents 10% of lactation and live weight gain. The OVERSEER® algorithm to calculate pregnancy already allows for this augmentation.

Further investigation for the reason(s) for this preliminary result revealed that the OVERSEER® calculations for estimating ME requirements for 'grazing' contained some errors. As mentioned above the 'MEgraze' component estimates the ME requirements for animal movement (MEmove), for chewing (MEchew) and for general activity (MEactivity), with MEmove accounting for most of the originally observed differences between OVERSEER® and NZAgInv. We have now discovered that in the OVERSEER® equations for this MEmove component a 'relative stocking' parameter (as described in the OVERSEER® technical manual; Wheeler 2016) was in fact missing from the code. This relative stocking factor relates to the ratio of actual grazing density (TSR; number of animals/ha) to potential grazing density (SD; number of animals/ha). The OVERSEER® technical manual for animal metabolisable energy requirements indicates that the TSR/SD ratio values are based on Nicol & Brookes (2007): 0.07 for dairy and 1 for other animal types. However, the parameter 0.07 was not included in the actual code. Because the value for other animal types is 1, the omission of this parameter only affects the MEmove estimates for dairy cattle. Once this error was rectified in the OVERSEER® development version, the total ME requirements estimated using OVERSEER® and NZAgInv are almost identical (Table 1b). The error in the MEmove equation has been logged in the OVERSEER® system for updating the online version.

Table 1b. Revision of Table 1a to account for missing parameter in MEmove in OVERSEER® v 6.2.3

Annual estimates of dairy cow metabolisable energy (ME) requirements using the development version of OVERSEER® and NZAgInv for the "inventory" year 2013. Values in round brackets represent the % of total ME requirement. Values in square brackets represent the % difference between the OVERSEER® and NZAgInv estimates.

ME requirement	OVERSEER v 6.2.3 MJ ME/year	NZAgInv MJ ME/year	Difference MJ ME/year
Basal metabolism	16,756 (35%)	17,496 (37%)	-740 [-4%]
Grazing	2,242 (5%) *3,144 (7%)*[b]	3,777 (8%)	-1,535 [-68%] *-633 [-20%]*[b]
10% of Production[a]	1,863 (4%)	2,414 (5%)	-551 [-30%]
Lactation	23,681 (49%)	22,273 (46%)	1, 408 [6%]
Pregnancy	2,028 (4%)	1,870 (4%)	158 [8%]
Weight gain	1,248 (3%)	0 (0%)	1,248 [100%]
Total ME req	**47,818 *48,720*[b] (100%)**	**47,830 (100%)**	**-12 [-0.03%] *890 [2%]*[b]**

[a] for NZAgInv, this represents 10% of the sum of the ME requirements for lactation and pregnancy. This is a factor included to account for the fact that ME requirements can vary with feed intake (Ministry for Primary Industries 2016).
[b] values in italics represent the estimates when the missing parameter was set as 0.7 rather than 0.07 (see text)

It should be noted that in a review of the energy equations in NZAgInv, Bown et al. (2013) noted that "*The reasoning for the application of the relative stocking rate of 0.07* [compared with 1 for other animals] *in Nicol & Brookes (2007) is not clear. This may be a typographical error."* Bown et al. (2013) suggest that the TSR/SD ratio value could instead be 0.7 for dairy cows. It is unclear if this is indeed a typographical error in Nicol and Brookes (2007) and further investigation into this issue is clearly needed. However, if we assume a TSR/SD ratio of 0.7 for dairy cows, the ME requirement associated with grazing increases from 2,242 to 3,144 MJ ME/year (Table 1b) and the total ME requirement from 47,818 to 48,720 MJ ME/year. After making this change to the MEmove, the OVERSEER® and NZAgInv estimates would remain similar with the OVERSEER® estimate for total ME requirement only 2% higher than that of the unchanged NZAgInv estimate.

Despite the good agreement on total ME requirements between OVERSEER® and NZAgInv, there are still differences between the individual components of the estimated total ME requirements. A full comparison of all the ME algorithms in both OVERSEER® and NZAgInv may provide clarity on the reasons behind the differences, but such a comparison was not possible within the scope of this current project. In addition, due to limited access to the OVERSEER® code, we were unable to investigate if the implementation of the ME algorithms matched the way they are described in the technical manuals.

Possible reasons for the observed differences between the ME requirement estimates in OVERSEER® and NZAgInv, which should be further investigated, include: 1) OVERSEER® estimated different weight loss or gain each month compared to the inventory; 2), the two methods used different approaches to estimate the ME requirement for grazing; 3) the calving date in OVERSEER® (20 July) is different to the date in the inventory (1 August); 4) the lactation curve in OVERSEER® is different to the one used by the inventory (as discussed above); 5) different assumed development and birth weights for calves; 6) different approaches for estimating energy requirements for milk. We recommend a full and detailed comparison of the OVERSEER® and NZAgInv ME algorithms and their implementation.

Our results support the key conclusion by Pacheco et al. (2016) who reviewed the metabolic animal requirements module of OVERSEER®. They concluded that, while the general approach for estimating ME requirements is sound, the current implementation of a mix of equations from different models/sources needs to be fully assessed. We also strongly endorse their recommendation for more transparency and documentation on the underlying assumptions and rationale for the choice of the ME parameters and algorithms, and their implementation in OVERSEER®.

Other considerations

Our report focuses on comparing the OVERSEER® and NZAgInv algorithms for estimating ME and DMI requirements for dairy cattle as we were able to utilise and build on the previous analysis from Kelliher et al. (2015). It was not possible within the scope of the current project to also include assessment of the ME and DMI algorithms for other livestock classes. We strongly recommend that such an analysis is conducted in a future project.

In addition, the most recent NZAgInv submission (2017), the equations to estimate enteric CH_4 emissions for sheep have been updated. Previously, CH_4 emissions from sheep were estimated using CH_4 yield factors of 20.9 g CH4 per kg dry matter intake (DMI) for sheep > 1 year old and 16.8 g CH_4 per kg DMI for sheep < 1 year old. Updated sheep methane prediction algorithms were derived by (Swainson et al. 2016):

- ln(g CH_4/day) = 0.765 x ln(DMI) + 3.09; for sheep >1 year old
- ln(g CH_4/day) = 0.734 x ln(DMI) + 0.05 (metabolisable energy) + 2.46; for sheep <1 year old

OVERSEER® currently uses the original approach, and should, in time, be updated to reflect the recent changes in NZAgInv.

Finally, we suggest that the OVERSEER® algorithms for CH_4 (and N_2O) emissions from effluent management systems also require further investigation. However, as there is an ongoing debate about the adequacy of the current inventory method for estimating CH_4 emissions from effluent ponds, any changes in OVERSEER® should not be made until this issue has been resolved.

In summary

The results suggest that, once an error in OVERSEER® was corrected, the total ME requirements for dairy cattle estimated by OVERSEER® and NZAgInv differed by only 0-2%. However, larger differences exist between the two approaches for determining individual components of the estimated total ME requirements. We recommend a full and detailed comparison of the OVERSEER® and NZAgInv ME algorithms and their implementation for all main livestock classes.

As a result of the current project and the recognition that having full confidence in the ME and CH_4 algorithms is critically important, there is now initial agreement that full access will be given to a small working group (including modellers/programmers and animal, soil and system scientists) to systematically go through the code to ensure the choice and implementation of the ME equations are fully understood and justified, and to make recommendations for any changes to OVERSEER® and/or NZAgInv.

4.2 Nitrous oxide

As highlighted in Figure 1, dry matter intake (DMI) is a key input for estimating N_2O emissions from animal excreta. Any differences in the estimates of DMI between OVERSEER® and NZAgInv, as discussed in the previous section, will also result in difference in the N_2O emission estimates. In this section we focus mainly on comparisons between the N_2O emission factors (EFs) used in OVERSEER® and NZAgInv.

OVERSEER® allows three options for the choice of EFs:

1. 'Farm-specific EFs' based on soil water and temperature (this is the default setting).
2. 'Annual average EFs' with default EFs values largely the same as in NZAgInv.
3. 'Annual average EFs, seasonally adjusted' which proportions emissions across months based on soil moisture content as per option 1.

NZAgInv currently uses annual average EFs (i.e. option 2 above) and does not apply a seasonal adjustment. However, a recent analysis of the national EFs data-set (Kelliher et al. 2014; van der Weerden et al. 2016) showed that seasonality had a significant effect on the EF values for urine and dung, and the possibility for using seasonally adjusted EFs in NZAgInv is currently being investigated.

Furthermore, although it is well-recognised that soil water content is a key driver of N_2O emissions, implementation in NZAgInv of spatially or temporally disaggregated EFs based on this parameters is challenging as this requires spatial and temporal input data on soil water content across New Zealand. In contrast, OVERSEER® incorporates a hydrological sub-model that estimates soil water content on a daily basis, thus enabling 'seasonally adjusted' and 'farm-specific' EFs. Here we assess the implied N_2O EFs when selecting 'seasonally adjusted' and 'farm-specific' EFs in OVERSEER®, and compare these with the results from New Zealand field trials that underpin the EFs values in the NZAgInv.

4.2.1 Approach

To assess the suitability of OVERSEER® for estimating N_2O emissions, we used a range of existing OVERSEER® files from dairy, sheep and beef, and deer systems to back-calculate the implied N_2O EFs for the urine deposited during grazing and compared these with values measured in New Zealand field trials. Back-calculation of EFs requires knowledge of the N load onto paddocks (at a block level) and the associated N_2O emission from that N source on each block. Unfortunately, this level of detail is not included in the output from OVERSEER®. Therefore a specialised software tool was developed for this project that can interrogate output data from OVERSEER® files to generate block-level information. Results from the tool include, on a monthly and block level, N inputs of urine, dung, urea fertiliser and non-urea fertiliser (kg N/ha), estimates of N_2O emissions from urine, dung and fertiliser, and implied EFs from urine dung and fertiliser (i.e. EF_1, $EF_{3\ URINE}$ and $EF_{3\ DUNG}$, respectively)

OVERSEER® allows users to specify whether 'farm-specific N_2O emission factors' or 'annual emission factors' are employed. The annual EFs have default values that are the same as those in NZAgInv, except for the EF value for urea fertiliser, and the EF value for leached N (as stated in our Milestone 1 short report – see Appendix).

'Annual' EFs can either be the same annual average value for each month, or they can vary each month based on a 'seasonal adjustment' but with the weighted average being same as the average annual value. This seasonal adjustment proportions the EFs across the months, based on temperature and soil water content (see below).

Using the software tool developed for interrogating OVERSEER® output data, an analysis of implied EFs was conducted on two distinct sets of OVERSEER® files. The first set we will name as 'Pastoral farms across NZ on moderately well drained soils'. These files covered a range of dairy farms (farm systems 1-5; DairyNZ) located in four regions of NZ (Waikato, Taranaki, Canterbury and Southland), sheep and beef farms located in five regions (King Country, Taupo, Wairoa, Canterbury, West Otago) and deer farms located in two regions (Hawkes Bay, Southland). The files that were available all used the 'annual emission factors, seasonally adjusted' option. For a subset of the dairy farm files we also had versions where 'farm-specific' EF values were selected.

The second set of OVERSEER® files we had access to are collectively named 'Irrigated dairy farm on contrasting soils'. This set of files described an irrigated dairy farm consisting of a number of blocks spread over a broad range of soil drainage classes (well, moderately well, imperfect and poor). The files that were available spanned seven years under dairy production, providing a range of climatic conditions, with all files using either 'annual emission factors, seasonally adjusted' or 'farm-specific emission factors'.

4.2.2 Results

Pastoral farms across NZ on moderately well drained soils

The results for files adopting 'annual emission factors, seasonally adjusted' revealed that the monthly implied EFs for fertiliser (EF_1) and urine (EF_3) ranged between 0.0008 to

0.0242 for dairy and between 0.0002 and 0.0260 for sheep, beef and deer (Table 2). These results are consistent with results from New Zealand field trials that showed EFs with a mean and standard error 0.0116 ± 0.0020 from dairy urine, and 0.0055 ± 0.0019 for sheep urine (Kelliher et al. 2014).

For dairy, the monthly EFs had an irregular frequency distribution (Figure 3), suggesting the influence of the 'seasonal adjustment' can result in a monthly EF value that departs markedly from 0.01. A similar result was observed with the sheep, beef and deer farms. It is important to note that, although the mean annual EF value will still equate to 0.01 when selecting 'annual average EFs, seasonally adjusted', the monthly N excretion values will also vary, resulting in different total annual N_2O emissions compared with the 'annual average EFs' option.

Table 2. Statistics on implied monthly EF_1 and $EF_{3\ URINE}$ values calculated for Dairy, Sheep, Beef and Deer farms using OVERSEER® version 6.2.3 (development version) when 'annual emission factors, seasonally adjusted' is selected.

Farm type	Emission factor	No. of values	Arithmetic mean	Minimum value	Maximum value	SEM[A]
Dairy	EF_1	768	0.0100	0.0008	0.0242	0.0002
Dairy	$EF_{3\ URINE}$	768	0.0100	0.0008	0.0242	0.0002
Sheep, beef & deer	EF_1	2040	0.0100	0.0002	0.0260	0.0002
Sheep, beef & deer	$EF_{3\ URINE}$	2040	0.0100	0.0002	0.0260	0.0002

[A]SEM = standard error of the mean

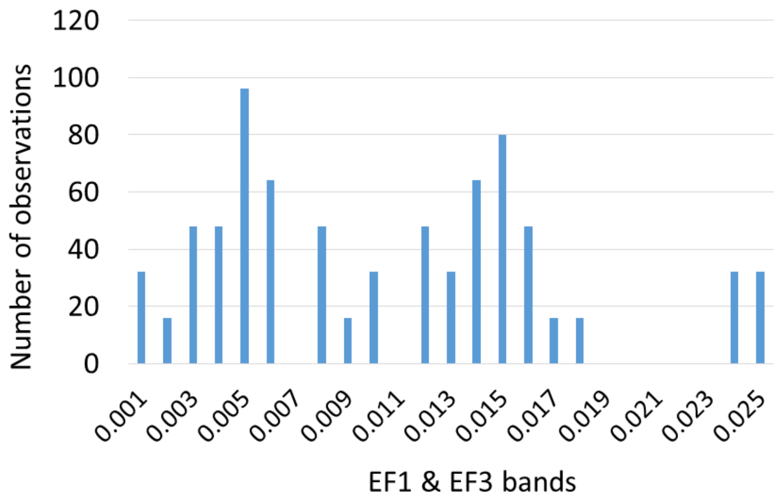


Figure 3. Frequency distribution of monthly EF_1 and $EF_{3\ URINE}$ for dairy farms when 'annual emission factors, seasonally adjusted' is selected

When selecting ‘farm-specific’ EF values (the default setting within OVERSEER®), EF values are determined according to temperature and soil water filled pore space (WFPS). WFPS is a function of the hydrology sub-model, which is driven by soil texture, rainfall/irrigation, evapo-transpiration and plant uptake, among other variables. As OVERSEER® is a farm-specific model, the use of farm-specific EFs is desirable as they would represent actual emissions. However, the underlying algorithms need to be scientifically robust and justified. For example, for N leaching OVERSEER has undergone some significant changes based on scientific research and now uses a site-specific method that accounts for soils and climate for estimating $Frac_{LEACH}$.

For our analysis, the dairy farm files where default ‘farm-specific’ EFs were selected were located in four regions with contrasting annual rainfall (Table 3). All dairy farm files were on a ‘moderately well drained’ soil, with the Waikato and Taranaki farms on ‘volcanic’ soil and the Canterbury and Southland farms on ‘brown’ soils. Our analysis showed that the mean $EF_{3\ URINE}$ values ranged from 0.0041 to 0.0151, increasing with increasing rainfall (Figure 4). The range of $EF_{3\ URINE}$ values across the four regions (0.0006 – 0.0238; Table 3) was similar to the range obtained from dairy farms where ‘annual emission factors, seasonally adjusted’ was selected (0.0008 to 0.0242; Table 2), therefore are consistent with the results from New Zealand field trials.

Table 3. Statistics on implied monthly $EF_{3\ URINE}$ values calculated for Dairy farms in four regions on moderately well drained soil using OVERSEER® version 6.2.3 (development version) when ‘farm-specific emission factors’ is selected.

Region	Rainfall (mm)	No. of values	Arithmetic mean	Minimum value	Maximum value	SEM[A]
Waikato	1139	192	0.0070	0.0006	0.0167	0.0004
Taranaki	1803	192	0.0151	0.0034	0.0238	0.0005
Canterbury	590	192	0.0041	0.0006	0.0072	0.0001
Southland	1025	192	0.0071	0.0006	0.0173	0.0004

[A]SEM = standard error of the mean

Our results also showed that, when the ‘farm-specific emission factors’ option was selected, the implied EFs for EF_1, $EF_{3\ URINE}$ and $EF_{3\ DUNG}$ were all the same. Therefore, the means and ranges shown in Table 3 for $EF_{3\ URINE}$ are the same for EF_1 and $EF_{3\ DUNG}$. For excreta, this contrasts with the values employed when ‘annual emission factors, seasonally adjusted’ is selected, where $EF_{3\ URINE}$ and $EF_{3\ DUNG}$ have values of 0.010 and 0.0025, which are the same values as being used in the NZAgInv. The OVERSEER®

model will therefore require modification to ensure $EF_{3\ DUNG}$ remains at 0.0025 when selecting 'farm-specific values' as there is currently insufficient data to support spatial or temporal disaggregation of this value.

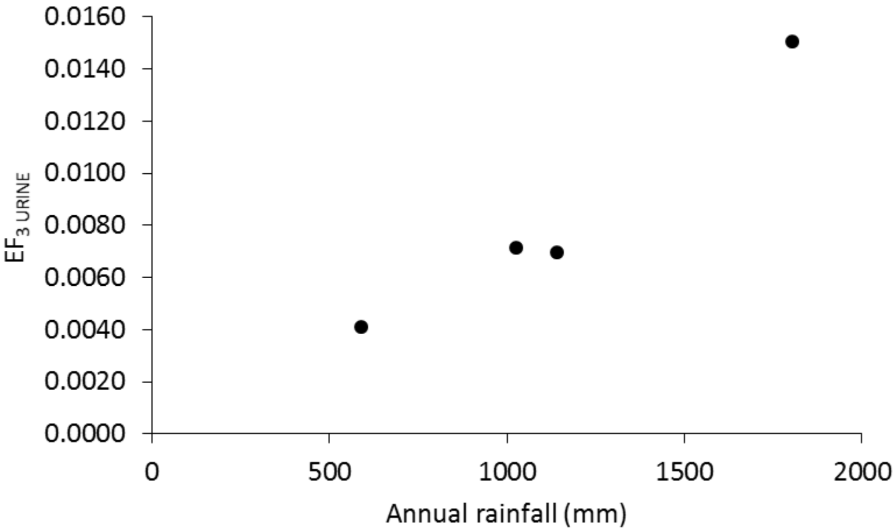


Figure 4. Relationship between annual rainfall (mm) and regional average $EF_{3\ URINE}$ for dairy farms in four regions on 'moderately well drained' soils when 'farm-specific emission factors' is selected.

Irrigated dairy farm on contrasting soils

Our second set of OVERSEER® files for an irrigated dairy farm revealed a similar range of implied $EF_{3\ URINE}$ values to those reported for dairy farms in Table 2 when the option 'annual emission factors, seasonally adjusted' was selected. Briefly, the mean, minimum and maximum values were 0.0100, 0.0009 and 0.0224, respectively (data not shown).

However, when the irrigated dairy had 'farm-specific emission factors' selected, the range of annual $EF_{3\ URINE}$ values increased markedly, with annual average values ranging from 0.0041 to 0.0682, depending on the soil drainage class (Table 4). When examining the data on a monthly basis, the range of mean values (i.e. average of 7 years) extends from 0.0006 for a well-drained soil in December to 0.1092 for a poorly drained soil in January (Table 4). The monthly variation in EF values is a consequence of monthly variation in temperature and soil WFPS. However, it appears OVERSEER® is over-estimating the actual EF values for soil other than well drained soils, with the average annual $EF_{3\ URINE}$ value being between 3.3 and 6.8 times higher than the NZAgInv values for the moderately, imperfectly and poorly drained soils (Table 4).

Table 4. Implied **monthly average** $EF_{3\ URINE}$ values calculated for an irrigated dairy farm at a block level (classified by soil drainage class) using OVERSEER® version 6.2.3 (development version) when 'farm-specific emission factors' is selected.

Month	Soil drainage class			
	Well (n=2)[A]	Moderately Well (n=4)	Imperfect (n=3)	Poor (n=3)
January	0.0017	0.0431	0.0374	0.1092
February	0.0022	0.0417	0.0333	0.0934
March	0.0030	0.0303	0.0598	0.0552
April	0.0039	0.0390	0.0751	0.0639
May	0.0057	0.0443	0.0671	0.0826
June	0.0056	0.0359	0.0554	0.0605
July	0.0061	0.0373	0.0570	0.0594
August	0.0062	0.0265	0.0438	0.0538
September	0.0059	0.0368	0.0608	0.0745
October	0.0049	0.0121	0.0237	0.0380
November	0.0032	0.0143	0.0190	0.0302
December	0.0006	0.0338	0.0397	0.0979
Annual Average	**0.0041**	**0.0329**	**0.0477**	**0.0682**
NZAgInv annual average	**0.0100**	**0.0100**	**0.0100**	**0.0100**
Ratio Annual average : NZAgInv annual average	*0.41*	*3.29*	*4.77*	*6.82*

[A] n = number of blocks with specified drainage class

The fact that January is producing the highest EF value is likely to be in response to the combined effect of high soil water content from irrigation and warm summer temperatures increasing N_2O production. As OVERSEER® is a site-specific model, N_2O emissions will vary with site-specific conditions and thus higher emissions can be expected in warm wet conditions. It is well recognised that WFPS is a key driver of N_2O emissions and the OVERSEER® technical manual for N_2O lists 13 field studies (as summarised by Barton et al. 1999) that were used as the basis for the relationship between WFPS and N_2O emissions (Wheeler 2015). However, the current implied emission factors for this farm are up to a factor of 10 higher than the range of values found in New Zealand research trials. Furthermore, more recent results have been published on significant relationships between WFPS and N_2O EFs for New Zealand soils under pasture as well as cropping (van der Weerden et al, 2012, 2014, 2017).The availability of these more recent research results, combined with the observed erroneous results in our study, warrants a review of the currently used relationship between N_2O emissions, temperature and WFPS in OVERSEER®.

A further and final point to note is that, as observed in the previous section, our data showed that selecting 'farm-specific emission factors' results in the implied EFs for EF_1, $EF_{3\ URINE}$ and $EF_{3\ DUNG}$ being identical. These EF settings will need to be de-coupled when 'farm-specific emission factors' are selected, to ensure that $EF_{3\ DUNG}$ remains at 0.0025.

Other considerations

In the 2017 submission of NZAgInv, the country-specific EF for urea fertiliser ($EF_{1\ UREA}$) will be revised to 0.0059. In addition, a hill country framework may in future be adopted to account for differences in N_2O emissions from sheep and beef on hill country, with EF_3 values being lower on hill land slopes. These adjustments to NZAgInv should, in time, also be incorporated into OVERSEER® to ensure ongoing consistency and alignment.

For non-livestock agricultural systems, N_2O emissions are driven by their N fertiliser use, and are determined from the total amount of fertiliser used and the associated N_2O EF. For urea fertiliser, OVERSEER® uses 0.01 whereas the NZAgInv used 0.0048 up until its 2016 submission, and 0.0059 from 2017 inwards. For non-urea N fertilisers, NZAgInv uses 0.01, whereas OVERSEER uses 1.2 to 1.5 times the urea EF (see Appendix for further detail). As the majority of studies on the N_2O EF for N fertiliser are conducted for urea that was applied to pastoral land, it seems appropriate that a review is commissioned on N_2O emissions from urea on non-pastoral land and non-urea fertilisers on all land uses, to determine appropriate EF values for a wide range of New Zealand agricultural systems.

In summary

The results suggest that the default setting for N_2O emissions in OVERSEER® ('farm-specific EFs') can lead to erroneously high N_2O emissions. Until further investigated and updated, this option should not be used. Although the implied emission factors for the option 'annual average EFs, seasonally adjusted' are consistent with the results from New Zealand field trials, the monthly proportioning of emissions is based on the algorithms used for the 'farm-specific EFs' option, and should therefore also be used with some caution.

Based on the above assessment it is recommended that,

- ‘Annual average EFs’ are set as the default option for calculating N_2O emissions in OVERSEER® and all EFs are the same as those in NZAgInv.
- ‘Farm-specific EFs’ and ‘Annual average EFs, seasonally adjusted’ are disabled until the algorithms underpinning these options are carefully reviewed, and experts are satisfied that currently available information is robust enough to justify their use.

As a result of the current project and the recognition that having full confidence in the N cycling and N_2O algorithms is critically important, there is now initial agreement that full access will be given to a small working group (including modellers/programmers and animal, soil and system scientists) to systematically go through the code to ensure the choice and implementation of the N_2O equations are fully understood and justified, and to make recommendations for any required changes to the code.

4.3 Accounting for mitigation options

Kelliher et al. (2015) assessed whether OVERSEER® could account for 10 available and potentially-available emission mitigation technologies, including options that reduce the EF for enteric methane, N fertiliser management options, low N feed, stand-off pads, reducing replacement rates, increase genetic merit while reducing cow numbers. They found that eight of these could already be implemented within OVERSEER® and that the remaining two (urease inhibitors and applying effluent when N losses are lowest) could be implemented with readily made changes to OVERSEER®, provided information on the effect of the technologies was available.

Similarly, Dynes et al. (2011) and Dennis (2016) showed that OVERSEER® could be used in combination with Farmax® to estimate GHG emissions from mixed livestock farms under a range of different management and mitigation scenarios (e.g. increasing lambing percentage, changing weaning percentage, reducing ewe replacement rates, hogget mating, having a younger breeding stock, once-bred heifers, replacing trading cattle with breeding hinds, and the use of summer fallow on 10% of the grazing area). Farmax® was used to initialise the farm scenarios and to obtain farm physical characteristics and livestock policies. These were then exported to parameterise the OVERSEER® files. Although only some of these scenarios showed an effect on total GHG emissions or GHG emissions intensity, the analysis showed that, in combination with Farmax®, OVERSEER® was able to analyse these alternative systems. Dennis (2016) also provides a list of data and information that should be collected to assess GHG emissions in OVERSEER®. This list is the same as that needed for assessing nutrient losses to water.

5. Process for ongoing calibration

The suitability of OVERSEER® for on-farm GHG reporting, and its alignment to NZAgInv, depends on calculations using the best available information. Consequently, OVERSEER® needs to be updated if better information becomes available. To better understand the effects of updating OVERSEER® on the calculated GHG emissions, we recommend the compilation and use of input data sets for the purpose of calibration.

Ongoing calibration of the GHG outputs across a range of farming systems can be closely aligned to suggested process for evaluation and re-calibration of the N leaching model in OVERSEER® as discussed by Shepherd et al. (2015). In their report, the authors give the following definitions of terms used for assessing model performance:

- ***Evaluation*** - All quantitative and qualitative methods for evaluating the degree to which a model corresponds to reality
- ***Validation*** - A comparison of model results with numerical data independently derived from experiments or observations of the environment (a part of the wider evaluation)
- ***Calibration*** - The process of adjusting numerical or physical modelling parameters in the computational model for the purpose of improving agreement with experimental data

Shepherd et al. (2015) suggested that the overall assessment of the performance of OVERSEER® requires investigation of four critical 'touch points' in the model. These 'touch points' or sub-modules need to be evaluated and calibrated separately, rather than relying on just comparing and aligning measured and modelled N leaching values (validation). These touch points are:

- Evaluate DM and N intake (assessing if the estimated DM and N intake are sensible based on e.g. expert opinion, common sense and/or statistical testing)
- Evaluate N excretion (assessing if the estimated amount and spatial and temporal distribution of N excreted are sensible)
- N leaching (assessing if the urine patch model and the proportion of N leached at urine patch scale are sensible)
- Estimates of N leaching (calibration and sensibility testing of N leaching estimates at the block level.

As DMI, N intake and N excretion are also critical parameters for estimating CH_4 and N_2O emissions, the first two steps are also key touch points for ongoing calibration of the GHG outputs. Once these parameters are estimated adequately, they are multiplied by CH_4 and N_2O EFs to estimate total CH_4 and N_2O emissions.

For CH_4, these EFs can easily be kept up to date as new experimental results become available and updated EFs are adopted in the NZAgInv. For N_2O, these EFs can also easily be up to date if the option 'annual average emission factors' is selected. When selecting 'annual average emission factors, seasonally adjusted' or 'farm-specific emission factors' the EFs depend on additional algorithms in OVERSEER®. For the 'annual average emission factors, seasonally adjusted' option, OVERSEER® adjusts the EFs on a monthly basis while ensuring that the annual average value remains the same. This requires an algorithm to apportion annual emissions across the months. The currently available data-set on seasonal EF values for urine (e.g. Kelliher et al. 2014) is a valuable resource and has already been used to refine the annual N_2O EFs in NZAgInv. As noted above, a recent analysis of the national EFs data-set showed that seasonality had a significant effect on the EF values for urine and dung (van der Weerden et al. 2016), and the possibility for using seasonally adjusted EFs in NZAgInv is currently being investigated. This EF data-set could therefore be used for calibrating the OVERSEER® algorithm for apportioning annual emissions across different months. It should be noted that the current NZAgInv structure already allows for the use seasonal EF values.

For the 'farm-specific emission factors', N_2O emissions are determined based on monthly temperature and soil water filled pore space (WFPS). This is based on algorithms that estimate WFPS and that link WFPS and temperature to total denitrification and N_2O emissions. These algorithms will require ongoing evaluation and calibration against experimental data. The current OVERSEER® algorithms appear to be based on pre-1999 results but new research data are available against which they can be evaluated (e.g. van der Weerden et al. 2012, 2014, 2017).

Based on current knowledge and understanding 'farm-specific EFs' or 'annual average, seasonally adjusted EFs' should not be used, until they are thoroughly reviewed and accepted. It is recommended that i) a process is defined to ensure reviews of relevant published research in these areas are conducted at regular intervals; and ii) a calibration data set is developed for validating the algorithms in OVERSEER® for apportioning annual N_2O emissions across the months and for determining N_2O emissions based on WFPS and temperature.

6. Process for ensuring ongoing alignment between OVERSEER and NZAgInv

6.1 Changes to the agricultural section of NZAgInv

In 2009, the New Zealand Ministry for Primary Industries (MPI) established an Agricultural Inventory Advisory Panel (AIAP). The Panel comprises representatives from MPI, the Ministry for the Environment and science representatives from the Royal Society of New Zealand, New Zealand Methanet and New Zealand NzOnet expert advisory groups. The AIAP is independent of policy and industry influences and has been formed to give advice on whether changes to New Zealand's agricultural section of the national inventory are scientifically justified. The AIAP assesses if the proposed changes have been appropriately researched, using recognised scientific principles and if there is sufficient scientific evidence to support the change(s). Once changes are agreed by the AIAP, they are sent to the Deputy Director-General (DDG) of MPI for consideration. MPI's DDG then recommends which changes should be presented to the Ministry for the Environment for implementation into the annual inventory (Figure 4).

6.2 Changes to OVERSEER

Proposed changes to or issues with OVERSEER® can be logged on the OVERSEER Ltd website. OVERSEER Ltd and the development team then prioritise these issues by rating them high, low or lowest. For major changes or developments, OVERSEER Ltd seeks advice from their Science Advisory Group (SAG) who will review the proposed change, and associated research to justify the change, and make a recommendation to OVERSEER®.

6.3 Ensuring alignment with changes to NZAgInv

Figure 5 identifies where in the process OVERSEER Ltd could be informed to ensure that any changes to NZAgInv that are relevant to OVERSEER® can be considered:

Step 1: OVERSEER Ltd is being made aware of any changes being reviewed by the AIAP. OVERSEER Ltd can then seek advice from its Science Technology Advisory Group on the relevance of these changes to OVERSEER®.

Step 2: OVERSEER Ltd is informed of the recommendations by the AIAP, and can, if assessed relevant, then consider what is required to make the change in OVERSEER®.

Step 3: OVERSEER Ltd is informed of the decision by MPI's DDG, and if approved by the DDG, will decide on the changes required in OVERSEER®. OVERSEER Ltd will then inform the team leader of MPI's Inventory team.

Step 4: If OVERSEER Ltd disagrees with proposed changes from the AIAP, OVERSEER Ltd and MPI meet to resolve the differences.

An alternative approach for steps 1 and 2 is that an OVERSEER® representative sits as an observer on MPI's Agricultural Inventory Advisory Panel meetings so they are fully aware and up to date on the discussions and recommendations on potential changes to NZAgInv.

6.4 Ensuring alignment with changes to OVERSEER

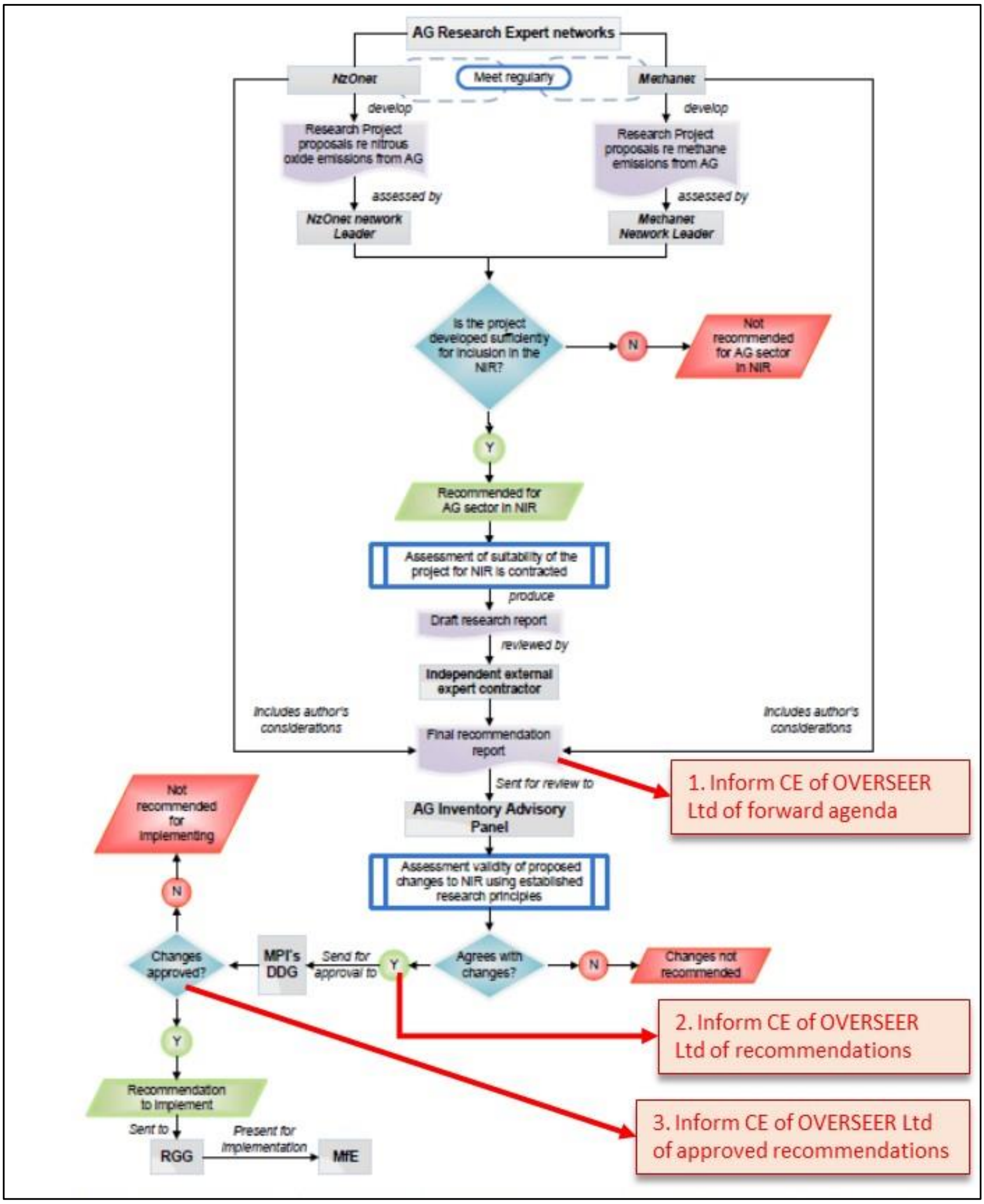
When changes to OVERSEER® are being considered, the following process is recommended:

Step 1: OVERSEER Ltd informs the team leader of the MPI's Inventory team of any recommendations it receives from the Science Technical Advisory Group for changes to OVERSEER®, and of the forward development and implementation agenda.

Step 2: MPI can then seek advice from its AIAP on the relevance of these to NZAgInv to decide whether any changes to NZAgInv should be considered.

Step 3: Once the changes to OVERSEER® are implemented, OVERSEER Ltd notifies the team leader of MPI's inventory team.

Step 4: If MPI's inventory team or the AIAP disagree with proposed changes from the OVERSEER Ltd, MPI and OVERSEER Ltd meet to resolve the differences.



Note: AG=Agriculture; NIR=National Inventory Report; DDG=Deputy Director-General; MPI=Ministry for Primary Industries; MfE=Ministry for the Environment; RGG=Reporting Governance Group (for the NIR).

Figure 5. Process for approving recalculations and improvements to the New Zealand agricultural methane and nitrous oxide inventory methodologies (Ministry for the Environment 2016); and identification of moments for informing the CE of OVERSEER Ltd about pending changes.

7. Conclusions and Recommendations

Overall, our assessment is that OVERSEER® is suitable for farm-scale GHG reporting because its general approaches and principles of calculating energy requirements, DMI and N excretion are supported by current understanding, and it can accommodate different farming systems and management practices. OVERSEER® also has the added advantage that the GHG emissions can be assessed without any additional work for farmers and farm consultants who are already using the model.

However, further investigations are needed to systematically analyse the code and the equations in OVERSEER® that are critical for estimating CH_4 and N_2O emissions, to ensure they are fully justifiable and also use the latest NZAgInv approaches and EF values.

Our conclusions are that:

- Adequately estimating ME requirements and thus DMI are critical for estimating CH_4 and N_2O emissions
- GHG estimates from OVERSEER® and NZAgInv are unlikely to be exactly the same as both models necessarily operate at different scales
- However, DMI, ME and N intake estimates are expected to be consistent with best available science/expert opinion
- The OVERSEER® approaches for calculating ME are consistent with the NZAgInv. However, our review has highlighted some errors/uncertainties that require further investigation. Also, as indicated by Pacheco et al. (2016), more transparency and documentation is required on the choice of equations and parameters for estimating ME requirements in OVERSEER®, and on the justification for deviating from the Australian feeding standards (CSIRO 2007) that are largely implemented in the NZAgInv.
- Although initial assessments suggested that there was about 10% difference in the estimates of ME requirements between the OVERSEER® and NZAgInv, further investigation revealed that one parameter had accidently been omitted from the MEmove equation in OVERSEER®. Once this parameter was added, the estimates of total ME requirements very similar for OVERSEER® and NZAgInv. This highlights the need for a thorough assessment of how the current GHG estimation routines are implemented in OVERSEER®.

- Seasonally adjusted N_2O EFs used in OVERSEER® are consistent with results from field studies, but N_2O emissions using 'farm-specific' EFs appear to be overestimated for some situations (e.g. on heavy soils under wet conditions). Until the 'farm-specific' EFs are fully evaluated, it is recommended that 'annual average emission factors' are used for assessing on-farm EFs.
- The suitability of OVERSEER® for on-farm GHG reporting is reliant on full confidence in the GHG estimates. The current project was somewhat hampered in its assessment of suitability, as we did not have full access to the OVERSEER® code. As a result of the current project and the recognition that having full confidence in the GHG algorithms is critically important, there is now initial agreement that full access will be given to a small working group (including modellers/programmers and animal, soil and system scientists) to systematically go through the code to ensure the choice and implementation of the equations that are critical for assessing CH_4 and N_2O emissions are fully understood and justified, and to make recommendations for any required changes to the code.

Our key recommendations are that:

- Following the initial agreement from OVERSEER Ltd to provide full access to the code, a small working group is commissioned to undertake a full assessment of all ME, DMI and GHG equations and their implementation in OVERSEER®.
- The equations and their implementation in OVERSEER® are evaluated for all New Zealand farming systems including dairying, sheep, beef, deer, horticulture and arable.
- 'Annual average EFs' are set as the default option for calculating N_2O emissions in OVERSEER® and all EFs are the same as those in NZAgInv.
- 'Farm-specific' and 'annual average, seasonally adjusted' EFs are disabled until the methods underpinning these options are carefully reviewed, and experts are satisfied that currently available spatial and/or temporal information is robust enough to justify their use.
- The rationale behind choice of equations and parameters for estimating ME, DMI and GHG emissions is fully documented in technical manuals.
- A calibration data set is developed for validating the algorithms in OVERSEER® for estimating DMI, N intake and N excretion, for apportioning annual N_2O emissions across the months, and for determining N_2O emissions based on soil moisture and temperature.

- OVERSEER Ltd and MPI's Inventory team discuss the proposed options for ensuring ongoing alignment between OVERSEER® and NZAgInv, and that the agreed approach is formally implemented.

Other, more detailed, recommendations are that:

- Updates on EFs and fractions as identified in our short report from January (see Appendix) are made as soon as practical.
- If 'farm-specific EFs' are accepted by experts, methods for decoupling $EF_{3\ URINE}$, $EF_{3\ DUNG}$, EF_1 and $EF_{1\ UREA}$ need to be included.
- A review is commissioned on N_2O from urea and non-urea fertilisers to determine appropriate values for a wide range of New Zealand agricultural systems.
- A process is established to ensure reviews of relevant published research are conducted at regular intervals and the potential implications for OVERSEER® are determined.

8. Acknowledgements

Caroline Read for valuable discussions on possible processes for ongoing alignment between OVERSEER® and NZAgInv, and for providing access to reports; Robyn Dynes for providing OVERSEER® files; and Harry Clark, Mike Hedley, Natalie Bartlett and David Pacheco for valuable comments on the draft report.

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10. Appendix – MS1 report submitted to BERG on 31/1/2017

Review of the existing assessment of the GHG component in OVERSEER Nutrient Budgets as reported by Kelliher et al. (2015).

Updated version following comments from BERG members

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Introduction

This short report provides the initial findings of a review of the existing assessment of the GHG component of OVERSEER® Nutrient Budgets (OVERSEER) compared with the New Zealand National Inventory (NZI) as reported by Kelliher et al. (2015).

We identify the extent to which issues raised in the Kelliher report have been subsequently addressed (see table 1 for an overview) and any new or additional modelling issues for GHG reporting relevant to policy development. We also provide further recommendations on the GHG component of OVERSEER.

It should be noted that this is a draft report and that, due to follow-up discussions or assessments, the recommendations may change for the final report.

It should be noted that OVERSEER and NZI operate at a different scale (farm vs national scale, respectively) and each have a different key purpose. For this review, we have assessed whether *the approaches* for estimating GHG emission in the models are consistent; with consistent being defined as 'the models each provide the best possible estimate of GHG emissions appropriate for the scale at which it is operating'.

It should also be noted that because of the different scales and purposes of the model, there could be differences in the importance/priority of a certain farm practice or farming type. For example, urea is the most common N fertiliser used in NZ and thus for the NZI it is most important to obtain an accurate N_2O EF for this fertiliser type, as other types have only a small effect on the estimated national emissions. However, for individual farmers that use N fertilisers other than urea, it is important that OVERSEER uses the best possible EF for these alternative N fertilisers.

Table 1: Summary table of issues raised by Kelliher et al. (2015), their current status and our recommendations

Issue	Description	Status	Recommendation
1. Dry matter intake (DMI)	OVERSEER estimated a 14% higher DMI than the NZI. Kelliher et al. (2015) concluded that the most likely reason is that OVERSEER calculates a greater energy requirement for cow maintenance than the NZI.	A subsequent review of the OVERSEER metabolic model (Pacheco et al. 2016) concluded that the principles of calculating energy requirements and DMI are supported, but that more transparency is required on the rationale behind the choice of equations and parameters.	Rationale behind choice of equations and parameters is provided and independently reviewed.
2. Emission factor (EF) for urea fertiliser (EF1)	OVERSEER uses 0.01 whereas the NZI used 0.0048 up until its 2016 submission. From 2017 onwards it will use 0.0059 For non-urea N fertilisers NZI uses 0.01, whereas OVERSEER uses 1.2 to 1.5 times the urea EF.	Change can be made, but because OVERSEER estimates the EF for other fertilisers as a proportion of the EF for urea, this will also change the EF for non-urea N fertilisers	Adjust the EF for urea to 0.0048; recognising that this will also impact on the EF for non-urea fertilisers. Commission a review on N_2O from non-urea fertilisers to determine appropriate values for New Zealand agricultural systems. Assess the cost of making structural and interface changes to the OVERSEER model to allow the use of separate EF values for all N fertilisers.
3. Emission factor for N leached (EF_5)	OVERSEER uses 0.025 whereas the NZI uses 0.0075	Change can be made and has been logged in OVERSEER system	Change to be made as soon as practical[2]
4. Fraction of N input that is	The default values in OVERSEER for	OVERSEER has since undergone some	This site-specific approach is

[2] This change is due to be made in the next release unless system testing identifies any major issues, but this is unlikely for this situation.

leached from the farm ($Frac_{LEACH}$)	$Frac_{LEACH}$ were 0.075 (for excreta) and 0.07 (for fertiliser), whereas the NZI uses 0.07 for both N sources.	significant changes and now uses a site-specific method that accounts for soils and climate for estimating $Frac_{LEACH}$. Default values for $Frac_{LEACH}$ are no longer applied.	appropriate for OVERSEER and no changes are required
5. CH_4 emissions from anaerobic lagoons	The NZI method for estimating CH_4 from lagoons was updated in 2015; OVERSEER uses the pre-2015 method.	Change can be made and has been logged in OVERSEER system	Change to be made as soon as practical[1]. Commission a review on 1) the applicability of the *anaerobic lagoon* for *holding* ponds, and 2) the need for accounting for regional variability, or variability in waste management system
6. The fraction of fertiliser and excreta N volatilised as ammonia ($Frac_{GASF}$ and $Frac_{GASM}$, respectively)	<u>$Frac_{GASF}$</u> At the time of the Kelliher et al. (2015) report $Frac_{GASF}$, was 10% in both OVERSEER and NZI. <u>$Frac_{GASM}$</u> NZI uses 10% while OVERSEER uses a sliding scale from 10% to 20%	OVERSEER recently adopted a site-specific methodology for estimating volatilisation. OVERSEER estimates $Frac_{GASM}$ based on average monthly temperatures.	As OVERSEER is a farm-scale model, we recommend that the site-specific methodology is maintained. As OVERSEER is a farm-scale model, we recommend that the site-specific methodology is maintained.
7. Enteric CH_4 emissions for deer and minor animal classes	<u>For Deer:</u> OVERSEER uses 21.3 g CH_4/kg DMI, while NZI uses 21.25 g CH_4/kg DMI.	Change can be made and has been logged in OVERSEER system.	Change to be made as soon as practical[3]

[3] This change is due to be made in the next release unless system testing identifies any major issues, but this is unlikely for this situation.

	For minor animal classes: In Kelliher et al. (2015) comparison of the CH_4 factors is difficult to make as the OVERSEER and NZI values are in different unit	In this report we recalculated the values using the same units.	Where available, comparisons indicate consistency between models.
8. CH_4 emission factor for dung for major (dairy, sheep, beef and deer) and minor animal classes	For major animal classes OVERSEER values are rounded to two decimal points, whereas NZI uses 3 to 5 decimal points. For minor animal classes Comparison between values difficult to make as different units are used and also because OVERSEER uses 'goats' and 'other', while NZI splits 'other' into a range of other animal species.	Change can be made and has been logged in OVERSEER system. The 'goats' value OVERSEER uses refers to 'dairy goats'; non-dairy goats are included in 'other'. OVERSEER uses the same value for dairy goats as what is used for sheep. This seems appropriate.	Change to be made as soon as practical[2] The OVERSEER value for 'other' could be reviewed, and if needed, updated to the NZI values the different species, if faecal dry matter values are available for these species.
9. N excreted in urine vs dung	The equation used in OVERSEER to allocate excreted N between urine and dung was not available in public documentation. Kelliher et al. (2015) was unable to assess if any different from NZI.	Unpublished technical manual were obtained which showed that OVERSEER uses the same equation, but with slightly different parameters.	An update of the partitioning equation in OVERSEER to match the NZI equation will have no to very limited effect on N_2O emissions.

* N/A, not applicable

Methods

We used to following steps:

- Reviewed the recommendation in the Kelliher report and discussed these with the main author and with OVERSEER technical staff to identify which of the recommendations (a) have been addressed and where this is documented; (b) can be addressed with existing information and what plan is in place for this to happen; (c) can be addressed but will require additional research/investigation, or (d) cannot be addressed.
- Reviewed a recent report of animal metabolic model (Pacheco 2016), and a report that was conducted as part of the DairyNZ's Primary Growth Partnership (PGP) project: Managing on-farm GHG emissions (Vibart & Watkins, 2015) to identify additional issues and implications for the GHG component of OVERSEER.
- Provided key recommendations and potential issues relating to OVERSEER's role as a GHG reporting tool, to be considered when developing policy for meeting national GHG commitments.

Review of Kelliher report

1. Dry matter intake

Kelliher et al. (2015) used a dairy farm example to estimate dry matter intake (DMI) of milked dairy cows using both OVERSEER and NZI. For both models they used the same values for key input parameters such as live weight of a milked dairy cow, milk yield, fat and protein content, pasture metabolisable energy (ME) content, and pasture digestibility. As the NZI uses a lactation length of 304 days, the OVERSEER lactation length was also set to 304 days. However, OVERSEER estimates *daily* milk production for each day of lactation using a regression curve fitted to three years of data with an average lactation length of 263 days. If a different lactation length is selected OVERSEER adjusts the proportion of milk produced each day accordingly. However, for mobs with a lactation length of greater than 300 days, a minimum proportional value is used (Wheeler, 2015a).

Using this example, Kelliher et al. (2015) found that the OVERSEER DMI estimate was 14% higher than the NZI estimate. Although they could not examine the key reason for this difference because the publically available OVERSEER technical manual did not provide sufficient information. However, Kelliher et al. (2015) concluded that the most likely reason for the difference is that OVERSEER calculates a greater cow maintenance requirement than the NZI.

To better assess the reasons why OVERSEER and NZI estimated different DMIs for the dairy example, we will use the original OVERSEER file from the Kelliher et al. (2015) report to extract the detailed information underpinning the DMI estimate. We anticipate that this will provide further insights in what component(s) of the energy model may contribute most to the observed difference.

Following the Kelliher et al. (2015) report, Pacheco et al. (2016) reviewed the metabolic animal requirements module of OVERSEER. They concluded that although the general principles of estimating ME requirements are proven, the estimates are ultimately defined by the choice of equations and parameters. Pacheco et al. (2016) noted that the OVERSEER documentation generally lack details about the underlying assumptions and rationale for the choice of parameters and equations. This is important for comparison with NZI, particularly when equations deviate from the CSIRO 2007 feeding standard that largely used in NZI.

It is recommended that a clear rationale for the choice of parameters and equations is provided and that this is then independently reviewed by animal nutrition experts as being justifiable.

2. N_2O emissions from synthetic N fertiliser

There are 3 ways of calculating emissions from N fertiliser in OVERSEER; these are farm-specific emission factors based on soil water content (default), annual emission factors (based on the NZI but can be user-defined) and annual emission factor adjusted for seasonal variation (again, based on the NZI but can be user-defined). The latter two are intended to match the national N_2O inventory, and are therefore the focus of this review.

The direct N_2O emission factor for urea N fertiliser applied to soil ($EF_{1\text{-UREA}}$) was reduced from 1% to 0.48% in the 2015 New Zealand inventory, but is now being increased again to 0.59% of the 2017 Inventory. However, OVERSEER still employs the IPCC default value of 1%, therefore Kelliher et al. (2015) recommended this value is updated within OVERSEER. According to David Wheeler (pers. comm.) this is a relatively simple change. However, it is important to note that while the inventory employs two different EF_1 values for N fertiliser ($EF_{1\text{-UREA}}$ = 0.59%, and EF_1 for all other fertiliser = 1%; Ministry for the Environment, 2016), OVERSEER currently employs different EF_1 values based on the N form and mix. Specifically, urea and ammonium-based N fertiliser has an EF_1 value of 1%, fertiliser mixes that include both ammonium and nitrate have an EF_1 value of 1.2 times urea, while N fertiliser added as nitrate only has an EF_1 value of 1.5 times urea (Wheeler, 2015b).

These values are based on expert opinion (J. Luo) and are coded in the OVERSEER as ratios of each other i.e. 1:1.2:1.5. Consequently, updating EF_1 for urea to align with the inventory value of 0.59% will also affect EF_1 values for ammonium- and nitrate-based N fertiliser. Adopting unique EF_1 values rather than ratios for the different N fertilisers will require changes to the structure and interface of the OVERSEER model, which may require considerable effort (D. Wheeler, pers. comm.).

Given urea is the dominant N fertiliser used in New Zealand, representing *ca*. 85% of total N fertiliser use (Ministry for the Environment, 2016), we recommend that OVERSEER still proceeds with updating EF_1 to 0.59% in the full knowledge that this will also impact on EF_1 for ammonium- and nitrate-based fertiliser. However, we also recommend an assessment of the cost of making necessary structural and interface changes to the OVERSEER model to allow employment of individual EF_1 values for urea, ammonium- and nitrate-based N fertilisers. Lastly, we recommend a literature review of EF_1 for ammonium- and nitrate-based N fertilisers to determine appropriate values for New Zealand agricultural systems. A recent meta-analysis of EF_1 for urea fertiliser included such a review (van der Weerden et al. 2016) and therefore updating this information is estimated to be a small cost.

3. Emission factor for N leached (EF_5)

Kelliher et al. (2015) reported that the N_2O emission factor for N that leaches (EF_5) was changed in the NZI in 2015 from 0.025 to 0.0075, while OVERSEER still used the original value is 0.025. This is a straightforward change to make and has been logged within the OVERSEER system.

4. Fraction of N leached following N inputs to soils

The inventory currently assumes 7% of all N inputs (urine, dung, N fertiliser, effluent) is leached. Kelliher et al. (2015) report that the OVERSEER model uses a value of 7.5%. However since the writing of their report, OVERSEER has undergone some significant changes that has led to the development of a site-specific methodology making it more sensitive to soils and climate for estimating FracLEACH. Because OVERSEER is aimed at farm-scale assessment of nutrient inputs and outputs, we recommend that a site-specific methodology for estimating N leaching is more appropriate than adopting the national FracLEACH value of 7%.

5. Methane emissions from effluent ponds

Kelliher et al. (2015) recommended OVERSEER needs to be updated to incorporate the NZI calculation for methane emissions from effluent ponds. In 2015 the inventory calculation adopted the IPCC Tier 2 methodology, where the most appropriate classification of effluent ponds was 'anaerobic lagoons'. The CH_4 emission factor for effluent ponds was derived from the IPCC (2006, equation 10.23 and 10.24):

$$CH_4\ EF = (1 - ASH) \times B_o \times 0.67\ kg/m^3 \times MCF/100 \qquad (1)$$

Where EF is the CH_4 emission factor for dairy cattle (kg CH_4/kg FDM), ASH is the ash content of manure (8%, IPCC, 2006, default value), 1 – ASH is the volatile solids fraction of FDM, B_o is the maximum methane producing capacity for dairy cattle manure (0.24 m^3 CH_4/kg VS excreted), 0.67 is the conversion factor for m^3 CH_4 to kg CH_4 and MCF is the methane conversion factor for anaerobic lagoons (74%). The B_o and MCF parameters were based on dairy cattle in Oceania with an annual average temperature of 15 ^oC (IPCC, 2006).

A change in the calculations in OVERSEER has been logged so that emissions from dung added to a 2-pond system will match the approach used in the NZI. However, there are two issues that need to be examined. The first relates to the different pond types present on New Zealand dairy farms and whether CH_4 emissions from each type are similar. OVERSEER currently includes 2 types of pond: **2-pond system** and **Holding pond**. By adopting the NZ inventory methodology, based on the IPCC Tier 2 approach, OVERSEER will be assuming that the Tier 2 methodology is appropriate for all NZ pond types, thus no difference between pond types. The second issue relates to site specificity: at a farm or regional-scale, to what extent will CH_4 emissions from effluent ponds vary, primarily due to storage period. Furthermore, how significant is the level of variation. If it is felt such variation needs to be captured at a site-specific scale, one option may be to apply different MCF values in equation 1 based on regional variation in the annual average temperature. For instance, at an annual average temperature of 10 ^oC, MCF is 66%, whereas at 20 ^oC MCF is 78% (Table 10A-4, IPCC, 2006). This difference can be readily captured by OVERSEER as annual average temperature is a parameter used within the model

6. *Fraction of N volatilised following N inputs to soils (*$Frac_{GASF}$ and $Frac_{GASM}$)

Kelliher et al. (2015), citing Wheeler et al. (2008), stated that $Frac_{GASF}$, the fraction of N fertiliser lost as ammonia (NH_3), is 10% in both the inventory and OVERSEER and is therefore aligned. However, OVERSEER has undergone changes recently, including a site-specific methodology for calculating $Frac_{GASF}$ for fertiliser based on fertiliser type, soil, climate and crop cover (Wheeler and Watkins, 2014).

The inventory uses a value of 10% for $Frac_{GASM}$, the proportion of N excreta applied to soil lost as NH_3 via volatilisation. In contrast, the OVERSEER urine patch model uses a sliding scale from 10% to 20%, depending on the average monthly temperature at the time of excreta urine N is deposition. Hence, OVERSEER has adopted a method that allows for variation across the country.

As for $Frac_{LEACH}$, because OVERSEER is aimed at farm-scale assessment of nutrient inputs and outputs, we recommend that the site-specific methodology for estimating N volatilisation from fertiliser and animal excreta is maintained.

7. Enteric methane emission for DEER and minor animal species

Kelliher et al. (2015) noted that in OVERSEER the CH_4 factor for Deer was 21.3 g CH_4/kg DMI, while NZI uses 21.25 g CH_4/kg DMI. This is a straightforward change to make and has been logged within the OVERSEER system.

For minor animal species, a direct comparison between the enteric CH_4 values used in OVERSEER and NZI was difficult to make as they are reported with different units: g CH_4/kg DMI, kg CH_4/RSU and kg CH_4/head. RSU refers to a Revised Stock Unit that consumes 6000 MJ ME per year. The reason for the different units is that the equations used in the two models require different data inputs. In table 2 we have first converted all OVERSEER emission values reported by Kelliher et al. (2015) to kg CH_4/RSU. By comparing these with the NZI values per head, we have inferred a RSU/head for each species. For goats and horses, we compared these RSU values with published values on RSU/head, indicating that OVERSEER and NZI values are consistent.

Table 2:

	Annual enteric methane values			Inferred RSU/head from comparison OVERSEER and NZI	Published values on RSU/head
Animal species	OVERSEER g CH_4/kg DMI	OVERSEER kg CH_4/RSU*	NZI kg CH_4/head		
Goats	20.9	11.5*	8.5	0.74	0.5-0.8 [1]
Swine		1.5	1.06	0.71	n/a
Horses		1.8	18	10	6-14 [2]
Alpacas and Llamas	20.9	11.5*	8	0.70	n/a
Mules and Asses		1.5	10	6.67	n/a

*** Calculated based on Revised Stock Unit (RSU) consuming 6000 MJ ME per year; this been approximately equivalent to 550 kg DM/year intake; n/a = not available.**
[1] http://portal.beeflambnz.com/tools/benchmarking-tool/definitions;
[2] http://lifestyleblock.co.nz/lifestyle-file/livestock-a-pets/the-basics/item/800-livestock-units

8. *Methane emission factor for dung deposited to pasture*

Kelliher et al. (2015) noted that in OVERSEER the CH_4 factor for dung deposited to pasture for the major animal species has two decimal points, whereas more precise values are used (three to five decimal points). This is a straightforward change to make and has been logged within the OVERSEER system.

For minor animal species, a direct comparison between the CH_4 factors for dung used in OVERSEER and NZI was difficult to make as they are reported with different units due to the models relying on different input variables. OVERSEER uses g CH_4/kg Faecal Dry Matter (FDM); whereas NZI uses g CH_4/head. OVERSEER only uses the minor animal classes 'goats' and 'other', while NZI splits 'other' into a range of other animal species. The value OVERSEER uses for 'goats' refers to 'dairy goats'; non-dairy goats are included in 'other'. We are unable to convert the OVERSEER values to the NZI values as we don't have FDM values per head for dairy goats. However, OVERSEER uses the same value for dairy goats as what is used for sheep. This seems appropriate as dairy goats are a similar size to sheep and both are optimally fed to maximise production. The current value used in OVERSEER for 'other' encompasses a range of minor animal species and could be reviewed.

9. *N excreted as urine vs dung*

Kelliher et al. (2015) reported that OVERSEER estimated a 14% higher DMI than NZI. They also reported that annual N_2O emissions were only 9 or 12% higher in OVERSEER compared with NZI. As all N input parameters and values used Kelliher et al. (2015) concluded that the only logical reason for this discrepancy was the way OVERSEER apportions excreta N into urine or dung. They were unable to assess this as this equation was not documented in any of the publically-available information.

For the current report we obtained the not yet publically available documentation and compared the OVERSEER equation with the one used in NZI:

NZI: N excreted in urine (kg N/year) = [(10.5 × Nd) + 34.4] × Nex/100

OVERSEER equation: N excreted in urine (kg N/year) = [(11.9 × Nd) + 29.9] × Nex/100.
where Nd is dietary N content (%) and Nex is the amount of N excreted (kg N/year).

The NZI equation is based on a review by Luo & Kelliher (2010). Although both models use slightly different parameters, the OVERSEER parameters are very close to the uncertainty range provided by Luo & Kelliher (2010):

N excreted in urine (kg N/year) = [(10.5 (±1.1) × Nd) + 34.4 (±3.4)] × Nex/100

Furthermore, when plotted against typical pasture N content the proportion of total N excreted as urine is very similar (Fig. 1). When using the N content of 3.7%, as used by Kelliher et al. (2015), the proportion of total excreta N as urine calculated using the NZ inventory and OVERSEER equations were 73.3% and 73.9%, respectively. This very small difference cannot account for the apparent discrepancy between differences in DM intake versus differences in N_2O emissions.

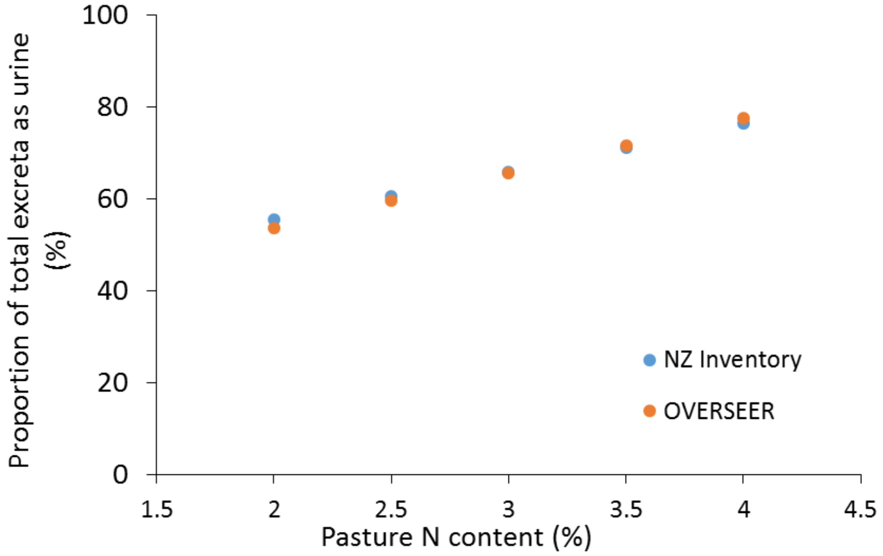

Fig. 1: Proportion of total excreta as urine, modelled using the NZ inventory and OVERSEER.

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