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Desk-top review of GHG components of OVERSEER®

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Desk-top review of GHG components of OVERSEER®

Draft report prepared for the New Zealand Agricultural Greenhouse Gas Research Centre

August 2015

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1. Executive Summary

This report responds to a request by the New Zealand Greenhouse Gas Research Centre (NZAGRC) for a desk-top review of greenhouse gas (GHG) emission calculations in the farm-scale nutrient budget model OVERSEER® v 6.2.0 (hereafter, OVERSEER®) and comparison with NZ's agricultural GHG emission inventory methodology. NZAGRC stipulated the review be conducted using publically-available information. OVERSEER® is one of the few tools widely used by farmers and their advisors which includes a farm-scale, annual estimate of agricultural GHG emissions. Agricultural emissions include the GHG gases methane (CH_4) from farmed ruminants and nitrous oxide (N_2O) from soils. The NZ agricultural inventory also estimates these emissions annually at a national scale. The national-scale emissions are calculated and reported annually by the NZ government in accordance with the United Nation Framework Convention on Climate Change.

The review had three objectives:

1) In comparison to NZ's inventory methodology, using publically-available information, list the GHG emission factors (EFs) used by OVERSEER®. With the input (activity) data used to calculate annual feed intake by the inventory methodology, calculate annual feed intake using OVERSEER® and compare the results. If necessary make recommendations to modify EFs, activity data and the animal feed intake estimates in OVERSEER®.
2) Develop a list of available and potentially available GHG emission mitigation technologies and conduct a desktop assessment using publically-available information to determine whether or not each can be implemented using OVERSEER®. In addition, for technologies which cannot be implemented, describe the information and/or change(s) to OVERSEER® needed for implementation.
3) With the input (activity) data used to calculate annual GHG emissions by the inventory methodology, calculate annual GHG emissions using OVERSEER® and compare the results.

Assessment of OVERSEER® emission factors and animal feed intake

Key findings – For OVERSEER®, the 'annual' N_2O emission factors (EFs) are based on those used in the year 2011 inventory which was publically released in April 2013. For the year 2013 inventory, two EFs changed substantially ($EF_{1\text{-urea fertiliser}}$ and EF_5 for nitrogen leached beyond soils) and they should be updated in OVERSEER®. The facility in OVERSEER® to adjust the direct N_2O EFs on a monthly basis according to calculated soil water content is not compatible with the inventory methodology. The OVERSEER® technical manual on N_2O emissions (Wheeler 2015c) did not include the values of other parameters used by the inventory methodology.

For OVERSEER®, the default enteric CH_4 EFs are the same as those used by the inventory for sheep and cattle. However, the OVERSEER® methodology for estimating CH_4 emissions from anaerobic lagoons needs to be updated.

Using the same input (activity) data for OVERSEER® and the inventory methodology including live weight, milk production and pasture metabolisable energy (ME) content and digestibility, we found OVERSEER® calculated a 14% greater annual feed (pasture dry matter) intake for dairy cows. We think the most likely reason is OVERSEER® calculated a greater maintence ME requirement, but the OVERSEER® technical manuals did not provide sufficient information for us to be sure. There is therefore a need for greater transparency about the OVERSEER® methodology for calculating annual feed intake.

Implementing emission mitigation technologies using OVERSEER®

***Key findings* –** We found that 8 of 10 available and potentially-available emission mitigation technologies can be implemented using OVERSEER®. The exceptions were (i) apply N fertiliser with urease inhibitor (which is done by the inventory methodology) and (ii) apply effluent when N losses lowest (which is not done by the inventory methodology). We think changes to OVERSEER® could be readily made to enable implementation of these technologies, provided information on the effect of the technologies was available.

Dairy farm emissions calculated by OVERSEER® and the inventory methodology

***Key findings* –** For annual enteric CH_4 emissions by dairy cows estimated by OVERSEER®, the mean was 14% greater than that by the inventory methodology. This difference was due to OVERSEER® calculating a 14% greater annual DMI because the two methodologies used the same EF (21.6 g CH_4/kg DMI). We cannot directly calculate the total N_2O emissions attributable to dairy cattle by the inventory methodology because the available data for N fertiliser applied to soils includes cropland and grassland (ie, no data are available at a national level for N fertiliser applied to soils beneath pasture grazed by dairy cattle). However, we were able to use both methodologies to estimate the direct N_2O emissions from dairy cow excreta. Using annual N_2O EFs for OVERSEER®, the mean estimate was 12% greater than by the inventory methodology and the percentage was 9% using 'farm specific' EFs. As stated, the OVERSEER® estimate of DMI was 14% greater than that by the inventory methodology, so OVERSEER® should have calculated 14% greater excretion. The pasture's N content was 3.7% for both methodologies. However, from publically-available information, we were unable to determine how OVERSEER® estimates the proportion of total N excreted as urine N. By our comparison, we think this proportion is likely to be estimated differently to the inventory methodology. This seems the only logical reason why OVERSEER® estimated 12% or 9% greater direct N_2O emissions from dairy cow excreta when DMI is 14% greater.

2. Background

OVERSEER® is one of the few tools widely used by farmers and their advisors which includes a farm-based estimate of agricultural GHG emissions. For example, Fonterra are using OVERSEER® to estimate GHG emissions from dairy farms as part of their Sustainability Programme. By searching the publically-available information on OVERSEER®, we found its GHG emission calculations were first described by Wheeler et al. (2008). Subsequent descriptions are provided in Wheeler (2010), Wheeler et al. (2011, 2013), Shepherd et al. (2012a,b) and Wheeler and Bright (2015). In addition, the OVERSEER® web site provides a series of technical manuals for version 6.2.0 by Wheeler (2015a-k).

An inventory methodology is used to estimate NZ's agricultural GHG emissions (Pickering and Wear 2013). This methodology complies with guidelines developed by the Intergovernmental Panel on Climate Change (IPCC, http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html, accessed 20 August 2015). Thus, national-scale emissions are calculated and reported annually by the government in accordance with the United Nation Framework Convention on Climate Change (UNFCCC).

A desk-top review of the GHG components in OVERSEER® and comparison with national inventory methodology calculations is timely for a number of reasons:

1) Internationally, proposals for a comittment related to NZ's GHG emissions are being developed in preparation for a climate treaty meeting in Paris in December 2015,
2) Nationally, the government plan to review the Emissions Trading Scheme (ETS) in 2015,
3) If agriculture was included in NZ's ETS, GHG emissions from farms could be estimated using OVERSEER®,
4) The most recent national inventory report, submitted 10 April 2015 (Ministry for the Environment 2015), included a number of changes which we will show have not yet been made in OVERSEER®. For example, the methodology relies on EFs which have been determined by research trials and meta-analysis such as Kelliher et al. (2014). Research has also sought to improve the activity data and associated calculations including mitigation technologies such as urease inhibitors (Saggar et al. 2013).

3. Emission factors and animal feed intake

3.1 Emission factors

N_2O emission factors

For OVERSEER®, the N_2O EFs have been tabulated and described by Wheeler (2015c, Table 1, page 4). These EFs are based on the year 2011 inventory submission which was publically released in April 2013. Consequently, any changes in the EFs since April 2013 have not yet been made in OVERSEER®. Moreover, as shown in the following screenshot (Figure 1), OVERSEER® users need to choose which type of EFs will be used for their calculations. Annual EFs are constants called "default annual NZI factors" by Wheeler (2015c, page 3). For the inventory methodology, the N_2O EFs are means from field trials, so for the calculations, they are constant throughout the year. In contrast, 'farm specific' EFs in OVERSEER® vary monthly according to the calculated soil water content (Wheeler 2015c, pages 5 – 12). However, on average for the year, we interpreted Wheeler (2015c) to indicate a 'farm specific' EF in OVERSEER® has the same value as an annual EF. In Wheeler (2015c), we could not find a description of "annual emission factors but adjusted seasonally" shown in the screenshot. Wheeler (2015c, page 4) also indicates users can replace the "default annual NZI factors" by different values of their choice.

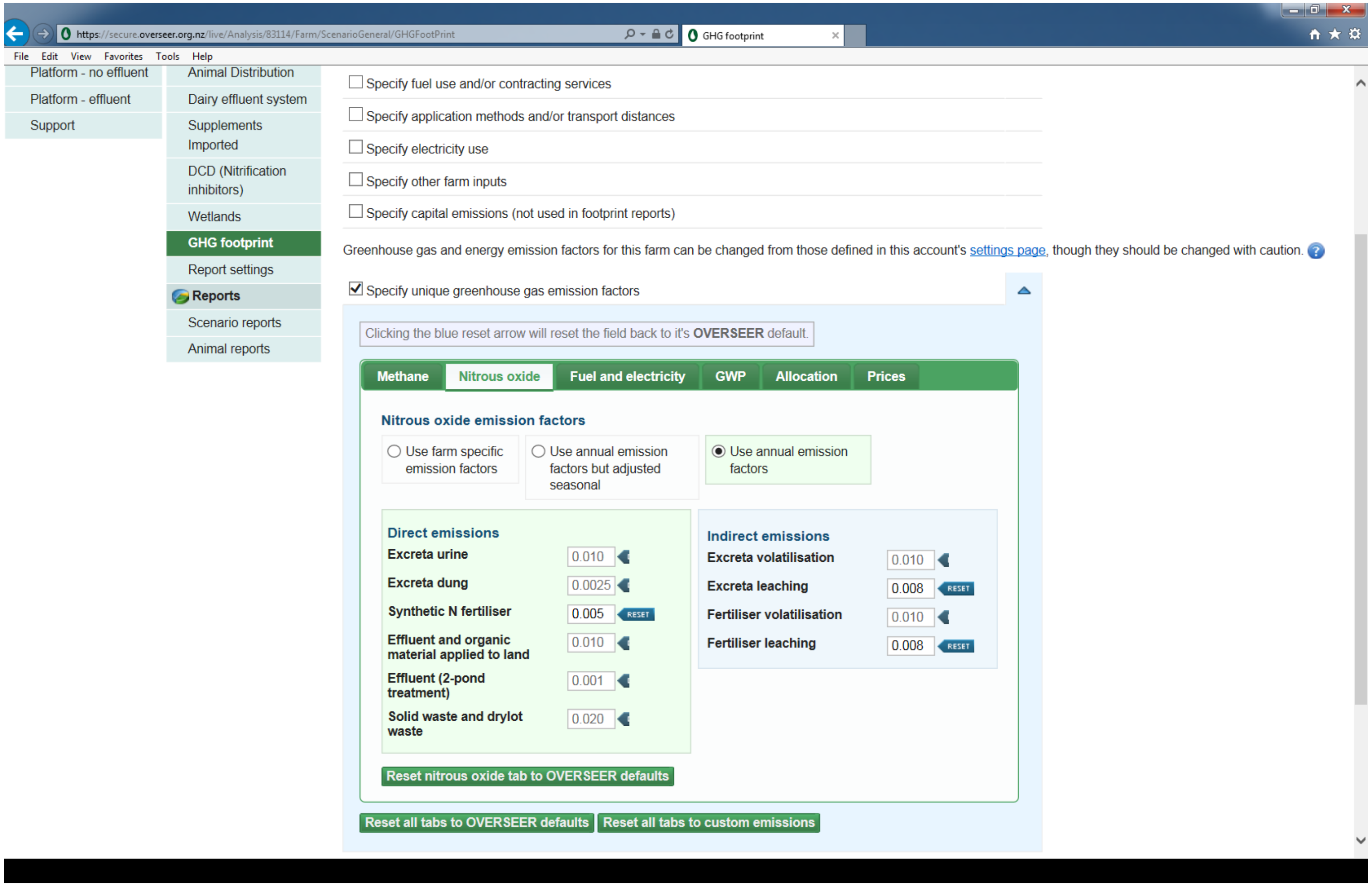

Figure 1 Screenshot of the OVERSEER® menu for our first set of calculations of the N_2O emissions from agricultural soils on a dairy farm indicating that we chose to use "annual emission factors" (EFs). For the EFs, we entered values used by the inventory methodology, but on the screen, $EF_{1\text{-urea fertiliser}}$ was truncated from 0.0048 to 0.005 and EF_5 from 0.0075 to 0.008

For OVERSEER®, the "default annual NZI factors" are the same as those used by the inventory methodology (Table 1) with two exceptions. The indirect N_2O EF for N excreta and fertiliser which leach beyond soils is EF_5 which was reduced for the year 2015 inventory from 0.025 to 0.0075 (Ministry for the Environment 2015, Table 5.5.2, page 163). OVERSEER® still uses a value for EF_5 of 0.025 according to Wheeler (2015c) and Wheeler et al. (2008).

The direct N_2O EF for urea N fertiliser applied to soils is $EF_{1\text{-urea}}$ which was reduced for the year 2015 inventory from 0.01 to 0.0048. For all other forms of N fertiliser such as nitrate and ammonia, EF_1 remains 0.01 (Ministry for the Environment. 2015, Table A3.1.2.3, page 424). A value of 0.0048 for EF_1 for urea was based on NZ field trial meta-analysis results reported by Kelliher et al. (2014). Although Wheeler (2015c, page 13) suggests that OVERSEER® uses a method based on the inventory to determine direct N_2O emissions from N fertiliser applied to soils, $EF_{1\text{-urea}}$ has not been changed from 0.01 to 0.0048. If we have understood equation 19 on page 12 of Wheeler (2015c) correctly, for OVERSEER®, users can specify an "annual, default inventory value" for EF_1. From equation 25 and Table 1 in Wheeler (2015c), for OVERSEER®, the annual, default inventory value for EF_1 will be 0.01 for urea fertiliser. Thus, the annual, default inventory value for $EF_{1\text{-yrea}}$ in OVERSEER® needs to be updated. Moreover, equation 25 on page 14 of Wheeler (2015c) indicates the annual, default inventory value for EF_1 will be 0.015 for nitrate fertiliser and 0.012 for mixtures of nitrate and ammonium fertiliser.

Table 1 N_2O EFs for N fertiliser and sheep and cattle urine and dung applied to soils.

Name	Emission factor		Units
	Overseer®[1]	Inventory[2]	
Direct			
$EF_{1 – urea fertiliser}$	0.01	0.0048	kg N_2O-N/kg N
$EF_{1 – other N fertilisers}$	0.01	0.01	kg N_2O-N/kg N
EF_2	8	8	kg N_2O-N/ha/year
$EF_{3PRP-urine}$	0.01	0.01	kg N_2O-N/kg N
$EF_{3PRP-dung}$	0.0025	0.0025	kg N_2O-N/kg N
Indirect			
EF_4	0.01	0.01	kg N_2O-N/kg NHx-N
EF_5	0.025	0.0075	kg N_2O-N/kg N

[1]Wheeler (2015c) citing values from the year 2011 inventory, [2]Ministry for the Environment (2015), Table A3.1.2.3, page 424, listing values for the year 2015 inventory

In Wheeler (2015c), we could not find a number of additional parameters used by the inventory methodology for calculating N_2O emissions (Table 2). For example, the inventory methodology uses the parameter FRACLeach to estimate the proportion of N applied to soils which leaches beyond soils. For the inventory methodology, FRACLeach is 0.07, a representative value actually estimated using OVERSEER® (Thomas et al. 2006). For OVERSEER®, Wheeler et al. (2008) indicated the default value was 0.07 for N fertiliser, but 0.075 for N excreta without explanation for the different value. For OVERSEER®, Wheeler et al. (2008) also indicated a default value for the inventory methodology parameter FRACGASF (proportion of N fertiliser applied to soils which volatilises as ammonia) is 0.1 which matches the value used by the inventory (Ministry for the Environment 2015, Table 5.5.3, page 163). However, a default value for the inventory methodology parameter FRACGASM (proportion of N excreta applied to soils which volatilises as ammonia) was 0.2 in Wheeler et al. (2008) or twice the value used by the inventory (Ministry for the Environment 2015, Table 5.5.3, page 163).

Table 2 Parameters used to calculate N_2O emissions from agricultural soils by the inventory methodology.

Name	Value[1]	Units
$Frac_{GasF}$	0.1	kg N/kg N
$Frac_{GasM}$	0.1	kg N/kg N
$Frac_{LEACH}$	0.07	kg N/kg N
$Frac_{BURN}$	Crop specific	kg N/kg crop-N
$Frac_{BURNL}$	0	kg N/kg crop-N
$Frac_{RENEW}$	Year specific	kg N/kg crop-N
$Frac_{REMOVE}$	0	kg N/kg crop-N

[1]Ministry for the Environment (2015), Table A3.1.2.4, page 424

CH_4 emissions factors

In Tables 3 – 5, we compare the CH_4 EFs used by OVERSEER® with those used by the inventory methodology.

Table 3 Enteric CH_4 EFs (g CH_4/kg DMI)[1] for sheep, cattle and deer.

Species	Overseer®[2]	Inventory[3]
Dairy cattle	21.6	21.6
Sheep (>1 year old)	20.9	20.9
Sheep (<=1 year old)	16.8	16.8
Beef cattle	21.6	21.6
Deer	21.3	21.25[4]

[1]Pickering and Wear (2013, page 26) also use the phrase "CH_4 conversion rate" i.e. the CH_4 emissions per unit of feed intake (g CH_4/kg DMI), [2]Wheeler (2015b, Table 1, page 4. NB: page 3 states "The default enteric methane emission factors shown in Table 1 can be modified for each animal class by the user." This cannot be done using the inventory methodology. The values in Table 1 of Wheeler (2015b) cite the 2011 national Table 6.3.2) which means the EF for deer used by OVERSEER® is different to that in the current NIR (Ministry for the Environment 2015), [3]Ministry for the Environment (2015), Table 5.2.2 and text, page 143, [4]Ministry for the Environment (2015), page 143.

Table 4 Enteric CH_4 EFs for minor animal species. For OVERSEER®, the units are g CH_4/kg DMI for goats, alpacas and llamas and kg CH_4/RSU/y for swine, horses, mules and asses with RSU denoting relative stock unit. For the inventory methodology, the units are kg CH_4/head/year.

Species	Overseer®[1]	Inventory[2]
Goats	20.9[3]	8.5
Swine	1.5[4]	1.06
Horses	1.8[5]	18
Alpacas and Llamas	20.9[6]	8
Mules and Asses	1.5	10

[1]Wheeler (2015b), [2]Ministry for the Environment (2015), [3]Wheeler (2015b) refers to the year 2011 inventory, [4]Wheeler (2015b) provides no source (ie, Reference) for this EF, [5]Wheeler (2015b) no source (ie, Reference) for the stated equivalence of 1 head (horse) to 10 relative stock units (RSU's) which is the basis for this EF (ie, inventory methodology value of 18 divided by 10 RSU equals 1.8 kg CH4/head/year), [6]Wheeler (2015b) states camelids including alpacas should use the enteric CH_4 EF for adult sheep which has units of g CH_4/kg DMI.

Table 5 CH_4 EFs for dung deposited on pasture (g CH_4/kg DMI).

Species	Overseer®[1]	Inventory[2]
Dairy cattle	0.98	0.98198
Sheep	0.69	0.691
Beef cattle	0.98	0.98198
Deer	0.92	0.915
Minor species		
Goats	0.69	0.18
Other	0.69	No data
Swine	No data	5.94
Horse	No data	2.34
Mules and Asses	No data	1.1
Broilers	No data	0.022
Layers	No data	0.016
Other poultry	No data	0.117
Alpacas and Llamas	No data	0.091

[1]Wheeler (2015b), [2]Pickering and Wear (2013) and Ministry for the Environment (2015)

The inventory methodology for estimating CH_4 emission from anaerobic lagoons changed considerably for the 2015 submission to (i) address concerns about earlier calculations (Pratt et al. 2014) and (ii) comply with the IPCC guidelines (chapter 10, http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html, accessed 20 August 2015, Ministry for the Environment 2015, section 5.3.2, page 151). For OVERSEER®, Wheeler (2015b, section 3.2.1, page 8) describes the inventory methodology which was used prior to the 2015 submission. On this basis, we think these calculations in OVERSEER® need to be updated and described in a technical manual.

3.2 Animal feed intake

Methods and input data

At a national scale, the inventory methodology estimates the annual feed dry matter intake (DMI) of milked dairy cows. This is done using national-scale activity data from sources such as New Zealand Dairy Statistics 2013 – 14 (http://www.lic.co.nz/lic_Publications.cfm, accessed 20 August 2015). These data include the total number of milked dairy cows in NZ and monthly adjustment using a population model (Clark 2008). Thus, at national, annual scales, we can determine the mean DMI of milked dairy cows (kg DMI/cow/year). For the year 2013 inventory methodology calculations, the input data included mean live weight of a milked dairy cow (463 kg), the mean milk yield (4012 kg/cow/year), mean milk fat and protein contents (4.84 and 3.71%, respectively), mean pasture dry matter (DM) metabolisable energy (ME) content (11.46 MJ ME/kg DM) and the mean pasture DM digestibility (78.3%).

We can use OVERSEER® to estimate the annual feed intake of cows milked on a dairy farm. For comparison with the inventory methodology, we will use the same input data described above as well as national means for the number of cows in the herd which are milked and the effective area. Because the inventory methodology calculations are done on a calendar year (2013) basis, for OVERSEER®, we calculated means for herd size and effective area from 2 years of data for 2012 – 13 and 2013 – 14, keeping in mind the milking ‘year’ begins around mid-July and finishs around the end of May. These data came from New Zealand Dairy Statistics 2013 – 14 (http://www.lic.co.nz/lic_Publications.cfm, accessed 20 August 2015). National mean data are given in Table 2.2, page 7, for herd size and effective area including 2012 – 13 and 2013 – 14. On this basis, for OVERSEER®, we specified the herd had 408 cows and the effective area was 142.5 hectares.

For the OVERSEER® calculations, we set the farm's terrain to flat which was appropriate and should minimise the ME requirement for food gathering by grazing. The inventory methodology calculations of ME requirement for grazing are based on CSIRO (2007, equation 1.22, page 23). As indicated by Wheeler (2015a, equations 21 and 22, page page 9), the OVERSEER® calculations are based on Nicol and Brooke (2007, equation 3, page 167). While Nicol and Brooke (2007, page 151) stated CSIRO (2007) was their "basis", their equation 3 to estimate the ME requirement of grazing includes variables which are different to those found in equation 1.22 of CSIRO (2007).

To accurately estimate the (mean) feed intake of dairy cows, accounting for the ME requirement of lactation (l) is vital. As stated, to compare the calculations of feed intake by milked dairy cows, the same input data will be used for the inventory methodology and OVERSEER®. In addition, we will briefly describe the inventory methodology and that publically-available for OVERSEER®. For the inventory methodology, we cite Pickering and Wear (2013), particularly their section 2.13, pages 6 – 7, while for OVERSEER®, we cite Wheeler (2015a) and Wheeler (2015d).

The inventory methodology begins by estimating the (ME) energy value of lactation (evl, MJ ME/kg milk) according to the milk's fat (F) and protein (P) percentages. Thus, we write equation (4) of Pickering and Wear (2013) as evl = [0.376 F] + [0.270 P] + 0.948 and identify the required activity data as national, annual means of F and P as noted above. The ME requirement of lactation (ME_l) depends on evl, milk yield and an ME intake efficiency coefficient for lactation (k_l), so we write equation (5) of Pickering and Wear (2013) as ME_l = (evl Y)/k_l. As explained after their equation (5), Y is calculated on a monthly basis from the national, annual milk yield and the proportion of annual milk yield each month (data given in their Appendix 4 on page 54). For the inventory methodology, dairy cows are in milk for 304 days each year (no milk in June and July). Term k_l is calculated monthly as [0.019 pasture ME content] + 0.42 using the monthly values of pasture ME content for dairy cattle in their Appendix 3 (page 53).

For OVERSEER® , evl is called "the NE value for dairy cow milk" (NE for net energy, Wheeler 2015d, page 30) which "can be calculated from the milk's fat and protein content according to Tyrrell and Reid (1965 (see their Table 4, equation 2, on page

1219)"(Wheeler 2015d, page 30). On this basis, we conclude evl is calculated identically by OVERSEER® and the inventory methodology. While for OVERSEER®, ME_l is calculated by the same equation as the inventory methodology, the proportion of milk yield each day of lactation is estimated differently. For OVERSEER®, the proportion of milk yield each day of lactation is estimated by a regression curve which was fitted to three years of data (years unspecified, but there were 263 days in milk on average) from Number 2 dairy farm in the Waikato region Wheeler 2015d, equation 39, page 27). For our comparative calculations with the inventory methodology using OVERSEER®, we entered 304 days in milk for the dairy cows.

Results and Discussion

Using OVERSEER®, the mean, annual feed intake was 4,758 kg DM/cow/year. Using the inventory methodology, the corresponding mean was 4,185 kg DM/cow/year. Thus, **the OVERSEER calculation of feed intake was 14% greater than the inventory methodology calculation**.

We think the most likely reason for OVERSEER calculating more feed intake is a greater estimate of the cow's maintence ME requirement. This argument is predicated on the two sets of calculations having used the same mean live weight, pasture ME content and digestibility and milk production data. As stated, OVERSEER calculated evl the same way as the inventory methodology according to our assessment of publically-available documents. However, as also stated, we had entered 304 days in milk rather than 263 days and the latter figure had been used to determine the time course of lactation for OVERSEER®. Moreover, as stated, for OVERSEER, we entered flat for the terrain to minimise the ME requirement for food gathering and possible differences between the OVERSEER® and inventory methodology calculations.

4. Implementing emission mitigation technologies

4.1 Assessment

We developed a list of available and potentially available GHG emission mitigation technologies (Table 6). By desktop assessment using publically-available information, we determined whether or not each can be implemented using OVERSEER®. We conclude that seven of the ten technologies can be implemented using OVERSEER®. The basis for each decision is described below. In addition, we determined whether or not each technology can be implemented using the inventory methodology. Provided a technology can be implemented using OVERSEER® and the inventory methodlogy, we then determined whether or not this is done differently by OVERSEER® compared to the inventory methodology.

Table 6 GHG emission mitigation technologies and whether or not each can be implemented using OVERSEER® and the inventory methodology.

Mitigation technology	OVERSEER®	Inventory
Reduce N fertiliser applied to soils	Yes	Yes
Apply N fertiliser with urease inhibitor	No	Yes
Apply nitirifcation inhibitor	Yes	Yes
Apply N fertiliser when N losses lowest	Yes	No
Replace some pasture with lower N feed	Yes	No
Use stand-off pad when N losses highest	Yes	No
Apply effluent when N losses lowest	No	No
Reduce animal stocking	Yes	Yes
Reduce dairy cow replacement rate	Yes	Yes
Reduce enteric CH_4 EF using inhibitor, vaccine, alternative feed (e.g., brassica) or animal selection	Yes	Yes

Reduce N fertiliser applied to soils

This mitigation technology can be implemented using OVERSEER® because the quantity of N fertiliser applied to soils can be altered (reduced) according to Wheeler (2015c). Moreover, on page 14 of Wheeler (2015c), equation 25 indicates the direct N_2O emissions from N fertiliser applied to soils depends on the the quantity of N fertiliser. On these bases, OVERSEER® seems to implement the first mitigation technology as done by the inventory methodology. However, as stated in section 3.1 of this report, OVERSEER® users need to choose which type of EFs will be used for their calculations.

For this section of the report, we assume users choose annual EFs which are constants called “default annual NZI factors”. Nevertheless, for N fertilisers, the inventory has two values of EF_1, 0.48% for urea and 1% for nitrate as well as ammounium fertilisers, while OVERSEER® has three values of EF_1 including 1% for urea, 1.5% for nitrate and 1.2% for mixtures of nitrate and ammonium fertiliser. Further, as stated on page 4 of Wheeler (2015e), OVERSEER® users must specify the month(s) when N fertiliser is applied to soils which is also different to the inventory methodology. Consequently, on these two bases, we conclude OVERSEER® implements this mitigation technology differently to the inventory methodology.

Apply N fertiliser with urease inhibitor

Evidently, this mitigation technology cannot been implemented using the current version of OVERSEER® because the effect of a urease inhibitor on the calculated N_2O emissions from N fertiliser applied to soils has not been described by Wheeler (2015c) or Wheeler (2012e). In contrast, as described in the 2015 national inventory report, beginning on page 172, the inventory methodology accounts for an effect of urease inhibitor on the N_2O emissions from N fertiliser applied to soils (Ministry for the Environment 2015). The inventory methodology seems suitable for OVERSEER®, so it will be described briefly. When a urease inhibitor was added to N fertiliser at a rate of 0.025% w/w and applied to soils, the fraction volatilised as ammonia (called FracGASF in the inventory) was reduced from 0.1 to 0.055 on average according to Saggar et al. (2013). A urease inhibitor was first used commercially in NZ in 2001 with the fertiliser company Balance AgriNutrient currently the sole supplier. For the 2015 national inventory report, Balance provided annual data for the years 1990 – 2013 of the mass of fertiliser N (urea) applied to soils with a urease inhibitor (Table 5.5.6, Ministry for the Environment 2015).

Apply nitrification inhibitor

This mitigation technology can be implemented using OVERSEER® because calculating an effect of the nitrification inhibitor dicyandiamide (DCD) on the N_2O emissions from soils was described by Wheeler (2015c). For grazing urine applied to soils, DCD reduces the direct N_2O emissions according to equation 23 on page 13 of Wheeler (2015c). However, the actual reduction has not been specified in this manual nor in any of the other publically-available documents we compiled for this project.

Alternatively, Shepherd and Wheeler (2012b) described the basis of the empirical approach taken in OVERSEER® to account for the effects of soil temperature and rainfall (drainage) on DCD effectiveness. The 2015 national inventory report describes the inventory's DCD methodology on pages 175 and 176 with the estimates for 2007 – 2012 reported in Table 5.5.7. After 2012, there was a voluntary suspension of DCD sales in NZ, so no mitigation estimates were reported for 2013. We do not know whether or not OVERSEER® implements DCD as a mitigation technology differently to the inventory methodology.

Apply N fertiliser when N losses lowest

This mitigation technology can be implemented using OVERSEER® because users must specify the month(s) when N fertiliser is applied to soils as indicated on page 4 of Wheeler (2015e). Moreover, according to equation (18) on page 12 of Wheeler (2015c), users can also specify farm specific monthly values of EF_1. The monthly values of EF_1 are estimated according to soil water balance calculations described by Wheeler (2015c,g,h,i) and Wheeler et al. (2015). In addition, the EF_1 estimates depend on a number of factors and equations calculating relationships between soil water content, temperature and de-nitrification rate described on pages 6 – 8 by Wheeler (2015c). The inventory methodology cannot implement this mitigation technology because the month(s) when N fertiliser is applied to soils cannot be specified.

Replace some pasture with lower N feed

This mitigation technology can be implemented using OVERSEER® because responses to user questions about the calculations associated with the use of supplemental feeds were provided by Power and Wheeler (2011). However, we could not find another publically-available document describing the methodology associated with supplemental feeds, a list of available supplemental feeds for the calculations or their N contents. This mitigation technology cannot be implemented by the inventory methodology because the use of supplemental feeds cannot be included.

Use stand-off pad when N losses lowest

This mitigation technology can be implemented using OVERSEER® because users can specify a stand-off pad as a farm structure as indicated on page 17 of Wheeler (2015j). While page 17 specifies animals will not be fed on a stand-off pad, there is no explanation for determining (entering) the time (period) animals will be placed on a stand-off pad. An OVERSEER® menu indicated users can specify the number of hours on the pad each day and percentage of the milking cows which stand on the pad. A stand off pad cannot be implemented as a mitigation technology using the inventory methodology.

Apply effluent when N losses lowest

Based on the information provided in publically-available documents, this mitigation technology cannot be implemented using OVERSEER®. Applying effluent to soils when N losses should be lowest was not described by Wheeler (2015c). While we did not find any reference to 'controlling' the timing of effluent application to soils in publically-available documents, an OVERSEER® menu indicates the months of effluent application can actually be chosen (Natalie Watkins, personal communication, 11 August 2015). Effluent application to soils when N losses should be lowest cannot be implemented as a mitigation technology using the current inventory methodology.

Reduce animal stocking

This mitigation technology can be implemented using OVERSEER® because users must specify the number of stock on a farm as indicated in Figure 7 on page 22 of Wheeler (2015i), so the number of stock can also be reduced. For the inventory methodology, stock population data are collected by Statistics New Zealand every five years by the Agricultural Production Census and annually between censuses by the Agricultural Production Survey (page 128, Ministry for the Environment 2015). Thus, if farmers reduce animal stocking, the inventory methodology can account for it and this mitigation technology.

Reduce dairy cow replacement rate

This mitigation technology can be implemented using OVERSEER® because users can specify the dairy herd (cow) replacement rate as indicated on page 34 of Wheeler (2015d). If the dairy cow replacement rate is not specified, a default rate of 23% will be used for the **OVERSEER®** calculations. Dairy cow replacement rate cannot be changed as a mitigation technology by the inventory methodology. As stated, for the inventory methodology, stock population data are collected annually by Statistics New Zealand. For dairy cattle, there are four categoriers including dairy cows and heifers which are 1 year and older and NOT in milk or in calf, dairy cows and heifers 1 year and older and in milk or in calf, breeding bulls and the total population (Clark 2008). Thus, if farmers reduce dairy cow replacement rate, the dairy cattle population will change and the inventory methodology can account for such change and this mitigation technology.

Reduce enteric EF using inhibitor, vaccine, alternative feed (eg, brassica) or animal selection

This mitigation technology can be implemented using OVERSEER®. While reducing the enteric CH_4 EF (ie, enteric CH_4 emissions per unit feed dry matter intake, DMI) using an inhibitor, vaccine, alternative feed (eg, brassica) or animal selection has not been described by Wheeler (2015b), as stated in section 3.1, users can choose/enter the value for an EF. Thus, the enteric CH_4 EF for dairy cattle could be reduced from the "default annual NZI factor" value of 21.6 g CH4/kg DMI (Table 1, page 4, Wheeler 2015b). On the same basis, the inventory methodology can implement this mitigation technology.

4.2 Implementation gaps

For OVERSEER®, the effect of a urease inhibitor on the calculated N_2O emissions from N fertiliser applied to soils has not been described by Wheeler (2015c) or Wheeler (2012e). This identifies an implementation gap. Urease inhibitor as an emission mitigation technology could be implemented by OVERSEER® using the inventory methodology described in the previous section.

While an **OVERSEER®** menu indicates the months of effluent application can actually be chosen, presumably including when N losses should be lowest, this potential mitigation strategy was not described by Wheeler (2015c). While we think the direct N_2O EF for effluent is not calculated monthly, this could readily be changed. Consequently, to implement, using OVERSEER®, the direct N_2O EF for effluent could be calculated monthly as described in sections 2.3 – 2.5 on pages 5 – 12 of Wheeler (2015c). Thus, OVERSEER® could be used to estimate when N losses from effluent applied to soils should be lowest.

5. Dairy farm GHG emissions

5.1 Calculations by OVERSEER®

There were two sets of calculations based on annual and farm-specific N_2O EFs. As stated, the annual N_2O EFs are constant throughout the year. In contrast, farm specific EFs can change from one month to the next depending on the calculated soil water content (see section 2.5 of Wheeler 2015c beginning on page 5). As shown by Figure 1 in section 3.1, when we set annual N_2O EFs to the same values used by the inventory methodology, the menu showed all values of the direct and indirect N_2O EFs. As shown by Figure 2 on the next page, when we set the farm specific N_2O EFs to the same values by the inventory methodology, the menu showed values of the indirect N_2O EFs, but not those of the direct N_2O EFs. Nevertheless, on average for the year, the farm-specific N_2O EFs had the same values as the annual N_2O EFs (David Wheeler, personal communication, 11 August 2015). However, the farm-specific N_2O EFs were adjusted each month by a factor determined by the calculated soil water content as described by Wheeler (2015c, sections 2.3 – 2.5, pages 5 – 12).

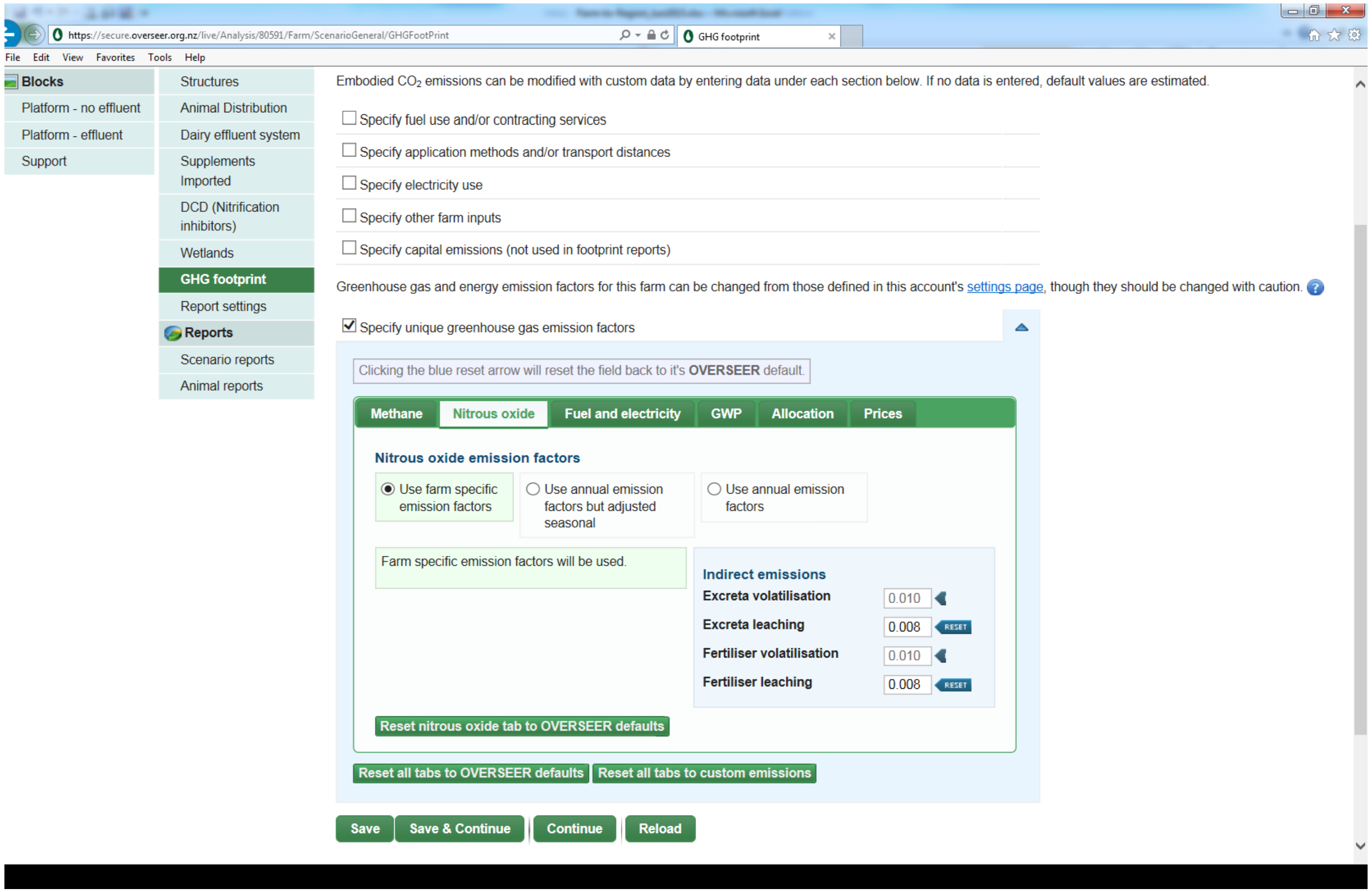

Figure 2 Screenshot of the OVERSEER® menu for our second set of calculations of the the N_2O emissions from agricultural soils on a dairy farm indicating that we chose to use "farm specific emission factors" (EFs). While we entered values for the EFs used by the inventory methodology, the values for "excreta leaching" and "fertiliser leaching" have been truncated from 0.0075 to 0.008 for display on the menu.

For both sets of calculations, we used the input data described in section 3.2 to make the emissions estimates by OVERSEER® as comparable as possible to that by the year 2013 inventory methodology. Briefly, as stated, the (mean) dairy cow live weight was 463 kg, milk yield was 4012 kg/cow/year, milk fat and protein contents were 4.84 and 3.71%, respectively, mean pasture dry matter ME content was 11.46 MJ ME/kg DM and mean digestibility 78.3%. We also set the farm's terrain to flat and in winter, all cows stayed on the farm.

For both sets of calculations, we set the rainfall range class to 2 and the seasonality class to 3 (Wheeler 2015h, Appendix 2, pages 34 - 45). For these settings, using the daily rainfall data in Wheeler (2015h, Appendix 2, Table 18), we calculated the annual rainfall to be 1139 mm. These settings were chosen to be representative of New Zealand because most of the country has an annual average rainfall between 800 and 1500 mm or 1150 mm on average (Tomlinson 1992).

For both sets of calculations, we chose the Brown soil order for all blocks of land. For pastoral soils, we estimated the area of Brown order soils represents nearly 40% of the total area (unpublished GIS overlay data not shown). For the next most widespread orders, we estimated Pallic soils covered 18% of the total area and Recent soils 11%.

For both sets of calculations, we set the potential evapotranspiration (PET) class to moderate and the soil drainage class to "well drained". Across NZ, most pastoral soils are well-drained (74% of the total area, page 167, Ministry for the Environment 2015). We set the topsoil texture to loam. We accepted the soil depth setting of 600 mm for water balance calculations and did not set drainage or rooting impediments at depths less than 600 mm.

5.2 Calculations by inventory methodology

As stated, the input data for these calculations were means for a class called mature milking cows for the calendar year 2013. We could not direct calculate the total N_2O emissions attributable to dairy cows by the inventory methodology because the available data for (inorganic N) fertiliser applied to soils (common reporting format, CRF Table 3.D, cell C9) includes cropland and grassland (ie, no data are available for N fertiliser applied to soils beneath pasture grazed by dairy cattle). However, we can calculate a mean dairy cow estimate of direct N_2O emissions from excreta deposited during grazing according to the inventory methodology for the calendar year 2013. For this alternative calculation, we determined a mean N excretion rate for dairy cows of 131.3 kg N/head/year. Of this, 5% is deposited during milking and goes to anaerobic lagoons, so 95% during grazing. (Ministry for the Environment 2015, Table 5.3.2, page 151). For dairy cattle excreta, the direct N_2O EF is 0.01 for urine and 0.0025 for dung (Ministry for the Environment 2015). To estimate the proportion of total N excretion as urine N, we use an equation developed by Luo and Kelliher (2010) for the inventory methodology; namely, Urine N% = [10.5 x pasture N content] + 34.4. For pasture grazed by dairy cattle, mean pasture N content is 3.7% for the inventory methodology (Pickering and Wear 2013). Consequently, we calculated that 73% of (urine + dung) N excreta is urine N excreta and 27% is dung N excreta. The direct N_2O emissions from urine is calculated as {[44/28] x 0.73 x 131.3 x 0.95 x 0.01} = 1.43 kg N_2O/head/year where [44/28] is molar mass ratio of N_2O and N_2. The direct N_2O emissions from dung is calculated as {[44/28] x 0.27 x 131.3 x 0.95 x 0.0025} = 0.13 kg N_2O/head/year. Combining, **the mean direct N_2O emissions from dairy cow (urine + dung) excreta deposited during grazing is calculated to be 1.56 kg N_2O/head/year**.

5.3 Comparison of OVERSEER® and inventory methodologies

Using OVERSEER®, enteric CH_4 emissions from the mean dairy cow was 14% greater than by the inventory methodology (Table 7). As stated, we obtained the same comparison of results for DMI (section 3.2). This reflects both methodologies using the same enteric CH_4 EF of 21.6 g CH_4/kg DMI.

Using OVERSEER® and annual N_2O EFs, the direct N_2O emissions from dairy cow excreta deposited while grazing averaged 12% greater than that by the inventory methodology. We were unable to determine how OVERSEER® estimates the partitioning of total excretion into urine and dung. If done differently to the inventory methodology, this could account for the different proportions by which the OVERSEER® calculations exceeded those of the inventory methodology for DMI and the direct N_2O emissions from excreta. Using OVERSEER® and farm specific EFs, the direct N_2O emissions from dairy cow excreta deposited while grazing averaged 9% greater than that by the inventory methodology.

Table 7 Mean GHG emissions from dairy cows calculated using OVERSEER® and the inventory methodology

	OVERSEER®[a]	**Inventory**
	kg/head/year	kg/head/year
Enteric CH_4 emissions	102.8	90.4
Direct N_2O emissions from excreta deposited on soils during grazing	1.74[a]	1.56[b]

[a]Does not include the direct N_2O emissions from excreta deposited during milking; Annual EFs were set to the same values used for the year 2015 by the inventory methodology; By a 2nd set of calculations using farm-specifc EFs as explained in the text, the emissions decreased to 1.70 kg/head/year, [b]Does not include the direct N_2O emissions from excreta deposited during milking.

6. Conclusions

The GHG emissions calculated by OVERSEER® and the inventory methodology are determined by the EFs. For OVERSEER®, the annual EFs are those used in the year 2011 inventory which was publically released in April 2013. Since then, some of the inventory methodology's EFs and the way of estimating CH_4 emissions from anaerobic lagoons have changed significantly. **OVERSEER® can be updated to account for changes in the inventory methodology.**

Using the same input (activity) data for OVERSEER® and the inventory methodology, we found OVERSEER® calculated a 14% greater annual feed intake for dairy cows. We think the most likely reason is OVERSEER® calculated a greater maintence ME requirement, but the OVERSEER® technical manuals did not provide sufficient information for us to be sure. **There is therefore a need for greater transparency about the OVERSEER® methodology for calculating annual feed intake.**

Nearly all the available and potentially-available emission mitigation technologies can be implemented using OVERSEER®. Moreover, changes to OVERSEER® could be readily made to enable implementation of the exceptional technologies, provided information on the effect of the technologies is available.

Using the same input (activity) data for OVERSEER® and the inventory methodology, we found OVERSEER® calculated a 14% greater annual enteric CH_4 emissions by dairy cows. This difference was due to OVERSEER® calculating a 14% greater annual feed intake because the two methodologies had the same enteric CH_4 EF. Using annual N_2O EFs, we also found OVERSEER® calculated a 12% greater direct N_2O emissions from dairy cow (urine + dung) excreta deposited during grazing. Using farm specific N_2O EFs, the percentage was 9%. From publically-available information, we were unable to determine how OVERSEER® estimates the proportion of total N excreted as urine N. **We conclude there is also a need for greater transparency about the OVERSEER® methodology for calculating annual N_2O emissions.**

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