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Detailed methodologies for agricultural greenhouse gas emission calculation

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Version control

Version	Author	Publish	Changes
1.0	Andrea Pickering	May 2011	First detailed methodology report
2.0	Simon Wear	August 2013	New methodologies and inclusion of new crops to estimate emissions from nitrogen-fixing crops and from crop residue; Changes to the emission factors and methodology used to estimate emissions from prescribed burning of savannas and field burning of agricultural residues. Revised methodologies and emissions factors for minor species, goats, swine and poultry Updated activity data appendices.

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1 Introduction

The international political response to climate change began with the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. The ultimate objective of the UNFCCC is to achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure food production is not threatened and to enable economic development to proceed in a sustainable manner. As at June 2013 the UNFCCC has been signed and ratified by 195 Parties, including New Zealand, and took effect on 21 March 1994.

However, the UNFCCC was not enough to ensure greenhouse gas levels would be stabilised at a safe level. In response the Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997. New Zealand ratified the Kyoto Protocol on 19 December 2002. The Protocol came into force on 16 February 2005. The Kyoto Protocol shares and expands upon the objective, principles and institutions of the UNFCCC. The objective of the Kyoto Protocol is to reduce aggregate emissions of six greenhouse gases from Annex I Parties to the UNFCCC (who had ratified, accepted, approved or acceded to the Protocol) by at least 5 per cent below 1990 levels in the first commitment period (2008-2012). Targets vary from Party to Party. New Zealand's target is to return emissions less removals from forestry as defined by article 3.3 of the Kyoto Protocol to 1990 levels on average over the first commitment period or otherwise take responsibility for the excess.

Under the UNFCCC and the Kyoto Protocol, Annex I Parties are required to monitor trends in anthropogenic greenhouse gas emissions. The annual inventory of greenhouse gas emissions and removals fulfils this obligation as well as providing transparency on how Parties are tracking towards their Kyoto Protocol targets. The Inventory reports emissions and removals of the six gases (carbon dioxide, nitrous oxide, methane, carbon monoxide, nitrogen oxides and non-methane volatile organic compound) from six sectors: Energy, Industrial processes, Solvent and other product use, Agriculture, Land Use Land-Use Change and Forestry (LULUCF), and Waste. The Inventory is submitted to the UNFCCC Secretariat by 15 April each year. Each inventory is reviewed to ensure emissions and removals, are estimated accurately and transparently (UNFCCC, 2010).

Methodological guidelines for reporting emissions and removals have been developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in response to climate change. Developing the methodologies used for reporting of GHG emissions and removals to the UNFCCC is one of the many activities that the IPCC undertake.

The first IPCC Guidelines were accepted in 1994 and published in 1995. The Kyoto Protocol reaffirmed that the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* should be used as "methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases" in calculation of legally-binding targets during CP1.

In 2000 in Montreal, the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (GPG2000) were accepted in response to the request from the UNFCCC for the IPCC to complete its work on uncertainty and prepare a report on good practice in inventory management. The GPG2000 do not revise or replace *the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, but provide a reference that complements and is consistent with those guidelines.

The Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF) is the response to the invitation by the UNFCCC to the IPCC to develop good practice guidance for Land Use, Land-Use Change and Forestry (LULUCF). GPG-LULUCF provides supplementary methods and good practice guidance for estimating, measuring, monitoring and reporting on carbon stock changes and greenhouse gas emissions from LULUCF activities under Article 3, paragraphs 3 and 4, and Articles 6 and 12 of the Kyoto Protocol. It was accepted by the IPCC Plenary at its 21st session held in Vienna 2003.

The Revised IPCC 1996 guidelines and IPCC good practice guidance and GPG-LULUCF are the current guidelines which are followed when estimating emissions and removals for the National Inventory. Further guidelines, the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, have been published but as yet have not been accepted by the Conference of the Parties for use in national inventory reporting. However, Parties can use the 2006 methodologies if they can adequately justify that it results in a more accurate estimate and can be shown to be appropriate to their national circumstances.;

Pastoral agriculture is a major component of the New Zealand economy, and pastoral agricultural products (excludes seafood and forestry) comprise 58 per cent of total merchandise exports (Ministry for Primary Industries 2012). Consequently, GHG emissions from pastoral agriculture make up around half of New Zealand's total emissions (excluding LULUCF).

The guidelines that have been developed by the IPCC have various levels of complexity which are based on the ability of a country to gather data and carry out improvements to their National Inventory, and the importance of the GHG source category. The most basic level is the tier 1 level. The methodology for tier 1 uses data which is not broken down into subcategories, for example, total sheep population rather than the population of ewes, rams, lambs etc. Also, the tier 1 methodology does not take into account country specific production data, rather assumptions around production are incorporated into default factors and population proportions for management systems. The default factors (called emission factors and fractions) and proportions are applied to basic data, such as population number, to calculate an estimate of GHG emissions from each sector.

The IPCC has developed these defaults using available information for world regions and are therefore not country specific. The IPCC guidelines encourage countries to improve the estimation of emissions by developing country specific emission factors, fractions and parameters through research and the use of country specific information. A more complex methodology, called tier 2, can be used if disaggregated population data and production data for a country is available. The basis of this tier 2 methodology for livestock emissions are the estimation of the energy requirements for cattle and subsequently the required dry matter intake. As methane and nitrous oxide emissions are related to the dry matter intake of an animal, these emissions can therefore be determined from the estimated dry matter intake.

There is also a third tier, tier 3, where countries are left to develop their own country specific models to estimate emissions form anthropogenic source. The tiered structure ensures that estimates are calculated at a detailed level that can be aggregated up to a common minimum level of detail for comparison with all other reporting countries

The tier 2 methodology developed by the IPCC for cattle is based on feeding systems with high levels of grain feed. In New Zealand 100 per cent of beef cattle and 95 per cent of dairy cattle are assumed to be pasture fed. Also, there is no tier 2 methodology for estimating the energy requirements for sheep and deer. Since 1990 milk per dairy cow and animal weights have all increased. Sheep also make up a large proportion of the total animals in New Zealand. Therefore New Zealand has developed its own tier 2 methodology (Inventory model) for determining the energy requirements of cattle, sheep and deer and subsequently the methane and nitrous oxide emissions from each species (Clark *et al*, 2003). This model was developed to conform to the IPCC good practice guidelines and is constantly under improvement. It takes into account the changing productivity of cattle, sheep and deer and provides a more accurate estimate of emission from New Zealand's key animal species compared to fixed default emission factors.

New Zealand has a favourable temperate climate, abundant of agricultural land and unique farming practices used in New Zealand. Most livestock are therefore normally born during July through to November (late winter to late spring). Farming practices are based on year-round extensive outdoor grazing systems and a reliance on nitrogen fixation by legumes rather than nitrogen fertiliser as the nitrogen source. For example, the majority (95 per cent) of dairy cattle and all (100 per cent) beef cattle, sheep and deer are grazed outside all year round. This means that New Zealand, like Australia, has a much lower proportion of agricultural emissions from manure management compared with other Annex 1 Parties, as intensive housing of major livestock is not practised in New Zealand. For further information of New Zealand's favourable agricultural growing conditions see chapters 1 and 2 (Executive summary and National Circumstances) of New Zealand's fifth national communication (http://www.mfe.govt.nz/publications/ climate/nz-fifth-national-communication/page3.html).

2 Energy requirement estimation

Data from Statistics New Zealand's annual Agricultural Production Survey (APS) and census, New Zealand Dairy Statistics, Beef and Lamb New Zealand and slaughter statistics collected by the Ministry for Primary Industries (MPI) are all used by the model to estimate energy requirements. Most of this data is collected on a June year end basis but the Inventory is calculated on a calendar year. Data is collected on a June year basis as this corresponds with the financial year for most New Zealand businesses. Therefore January–December values are calculated from two years worth of data; the last six months of one June year and the first six months of the next June year. As the Inventory model calculates emissions on a monthly time step this determination of a calendar year is possible. The population model has been developed by using industry knowledge and assumptions as detailed in Clark, 2008. This is carried out externally from the model itself and resulting population data for each subcategory of species feeds into the model calculations.

Nearly all animals in New Zealand are fed by grazing improved, planted pasture. As the default IPCC algorithms used for estimating energy requirements are based on grain fed animals, New Zealand's Inventory model uses the Australian Feeding Standards algorithms for cattle and sheep (CSIRO, 2007). These have been developed from freely grazing ruminants and therefore would better reflect the New Zealand feeding situation.

The metabolisable energy (ME) is the animal's energy intake less the losses in faeces, urine and methane. The ME is the "useful" energy made available by digestion and utilised for maintenance and (milk, meat and wool) production (Waghorn, 2007). A maintenance level (ME_m) will be determined by the amount of ME feed needed to maintain the animals live weight, a lower limit for the "machinery of life". The ME intake that exceeds MEm will be used for production. For grazing ruminants, ME_m cannot be measured, but methods for estimation have been developed including the Australian Feeding Standards (CSIRO, 2007). The ME content of forages can be determined from samples subjected to near infrared spectroscopy measurements (Corson *et al*, 1999)).

The general ME equation for cattle sheep, and deer (CSIRO, 2007, p.19; eqn. 1.19) is shown in equation 1.

$$ME_m(MJ/d) = K.S.M.\frac{0.28W^{0.75} \times \exp(-0.03A)}{k_m} + 0.1ME_P + ME_{GRAZE} + E_{COLD} \text{ (Equation 1)}$$

Where:

K = 1.0 for sheep and 1.4 for cattle

S = 1.0 for females and castrates or 1.15 for entire males

M = 1 for animals except milk fed animals. This factor has been removed in the New Zealand calculations and adjustment for milk fed animals is carried out through a milk adjustment factor detailed later.

W = Live weight (kg)

A = age in years, with a maximum value of 6

k_m = (net efficiency of use of ME for maintenance) 0.02 ME + 0.5 where ME is the metabolisable energy (MJ ME per kg dry matter per day) of pasture that has a gross energy content of 18.45 MJ per kg dry matter

ME_p = the amount of dietary ME being used directly for production (MJ ME per kg dry matter per day)

ME_{GRAZE} =Additional metabolisable energy expenditure of grazing compared with similar housed animals (MJ ME per kg dry matter per day). Determined by E_{GRAZE}/k_m

The first part of equation 1 can also be termed BASAL and will be referred to as such throughout the rest of this document. It is also generally accepted that ME varies directly with feed intake, and the allowance for this effect on maintenance requirement is a 10 per cent increment on the ME requirement for production, hence the term 0.1 ME_p in equation 1 (ME_p is the ME requirement for milk production, conception/gestation and live weight gain). E_{GRAZE} is then the additional energy expenditure of grazing compared with similar housed animals. In the original equation from CSIRO a term E_{COLD} is included in the equation. This has been removed for as it does not apply to the New Zealand situation.

As ME_p is the ME requirement for milk production, conception/gestation and live weight gain, the total ME of an animal is therefore simply the sum of ME_m and ME_p. In calculating the total ME for various different species and animal class' the ME_p component differs and therefore the 10 per cent increment of ME_p will also differ. Therefore, for transparency purposes the following equation is a better representation of the equation for total ME.

$$ME_{total} = BASAL + 1.1 \times (ME_p) + ME_{graze} \qquad \text{(Equation 2)}$$

Where:

BASAL = Metabolisable energy requirements to maintain animal weight (MJ ME per kg dry matter per day).

ME_p = the amount of dietary ME being used directly for production (MJ ME per kg dry matter per day)

ME_{graze} = Additional metabolisable energy expenditure of grazing compared with similar housed animals (MJ ME per kg dry matter per day).

The Inventory model determines ME and therefore dry matter intake, for an average day and then multiplies this by the number of days in each month to produce monthly values of ME for each animal. These monthly values are then multiplied by the monthly population for each livestock class calculated by the population model. Finally, the monthly estimates are added together to produce the estimates for the year. Specific details relating to each species are outlined in later sections.

2.1 DAIRY

The breakdown of livestock populations suggested for tier 2 calculations in the IPCC guidelines recommend cattle be split into mature dairy cattle, mature non-dairy cattle and young cattle. The definition of mature dairy cattle is “dairy cows used principally for commercial milk production”. All other cattle, including males for breeding and growing heifers, are defined under the other two categories. In reporting of the emissions from these categories only the emissions from mature dairy cattle are reported under dairy, and the emissions from the other cattle are reported under non-dairy.

However, for New Zealand’s Inventory the definition of dairy cattle includes all growing heifers which will be used for milk production, and the breeding bulls specific to the dairy industry, and therefore estimates emission for four classes of dairy cattle (Table 1). Emissions reported in the inventory under the dairy section therefore cover a broader range of animals than other countries inventories.

Table 1: Breakdown of subcategories used in dairy calculations

Region	Dairy cattle subcategories
01. Northland Region	1 Milking cows and heifers
02. Auckland Region	2 Growing females < 1 year old
03. Waikato Region	3 Growing females 1-2 years old
04. Bay of Plenty Region	4 Breeding bulls
05. Gisborne Region	
06. Hawke's Bay Region	
07. Taranaki Region	
08. Manawatu-Wanganui Region	
09. Wellington Region	
10. Tasman Region	
11. Nelson Region	
12. Marlborough Region	
13. West Coast Region	
14. Canterbury Region	
15. Otago Region	
16. Southland Region	

Productivity data for dairy is available at a regional level. Therefore to improve accuracy and to take into account regional differences, dairy calculations are carried out at a regional scale. Productivity data (milk yield and composition) is collected by the Livestock Improvement Corporation at the same territorial authority level as the population data is collected by Statistics New Zealand. This data is then aggregated up into the regional council regions. These regions are the same as that used by Statistics New Zealand, and therefore regional population data for the four dairy subcategories is taken from the Statistics New Zealand regional breakdown of dairy population.

All emissions from all classes are calculated on a monthly base.

2.1.1 Total energy requirements

The total energy requirement is made up of various components which depend on the physiological state of the animal. The basic equation was outlined in equation 2 and includes the term ME_p to account for the amount of dietary ME being used directly for production. The ME_p component for dairy cattle can be made up of the following components

ME_l = ME requirements for milk production

ME_c = ME requirements for conception/gestation

ME_g = ME requirements for live weight gain

Dairy animals which are less than 1 year old do not begin grazing until their third month of life. Until that time they are milk fed. Therefore they do not require the same amount of energy for grazing in that year and the total ME requirement needs to be adjusted for the reduced ME_{GRAZE}. This is done by including a further term, z_1, in the calculations for the total ME requirements.

The specific variables used in the calculation of total ME requirements for each class of dairy animal are outlined in Table 2.

Table 2: Equations for the total ME requirements for each category of dairy animal

Category	Output
Milking cows and heifers	Basal + 1.1 × (ME_l + ME_c + ME_g) + ME_{graze}
Growing females < 1 year old	(Basal + 1.1 × ME_g + ME_{graze}) – z_1
Growing females 1-2 years old	Basal + 1.1 × ME_g + ME_{graze}
Breeding Bulls	Basal + 1.1 × ME_g + ME_{graze}

The following section details the calculations for each component of the total ME equation for dairy.

2.1.2 Basal metabolisable energy requirements

$$\text{Basal} = K \times S \times \frac{(0.28W^{0.75} \times \exp(-0.03A)}{k_m} \qquad \text{(Equation 3)}$$

Where:

K = 1.4 for B. Taurus (CSIRO, 2007)

S = 1.0 for females and castrates or 1.15 for entire males (CSIRO, 2007)

W = Live weight in kg (Monthly live weight is determined by the program based on the final live weight in Appendix 1)

A = age in years (Appendix 2)

k_m = Net efficiency of use of ME for maintenance.

=0.02 × pasture ME content (Appendix 3) + 0.5

2.1.3 Milk production metabolisable energy requirements

As the equations in the Australian Feeding Standards require different variables than New Zealand collects (that is, fat and solids-not-fats versus fat and protein) an equation taken from the United Kingdom's Energy & Protein Requirements of Ruminants (Agricultural and Food Research Council (AFRC):1993) is used to determine the energy requirements for lactation. This equation has been adjusted to use percentage of fat and protein in milk as it is based on fat and protein values measured in grams of fat and protein per kilogram of milk. The net energy requirement for milk production is therefore determined by the following equation:

evl (MJ ME/kg milk) = gross energy content of milk

$$= 0.376 \times F + 0.209 \times P + 0.948 \qquad \text{(Equation 4)}$$

Where:

F = milk fat (percentage Appendix 1)

P = milk protein (percentage Appendix 1).

The suitability of this equation for the New Zealand situation can be demonstrated using New Zealand specific studies. Grainger *et al*. (1983) has shown that the relationship between the gross energy content of milk (evl) and its concentration of fat and protein has different parameter values for Holstein-Friesian and Jersey breeds. Using the relationship from this study for Holstein-Friesian and Jersey breeds, in 1990 evl was 3.31 and 3.64 MJ ME/kg respectively, averaging 3.48 MJ ME/kg. Due to a lack of suitable disaggregation of activity data it is not possible to use these New Zealand specific relationships in calculating emissions for the inventory. By using equation 4 the evl for 1990 was 3.49 MJ ME/kg, almost identical to that of the average of the two New Zealand specific equations.

Once evl is determined, metabolisable energy requirements for milk production can therefore determined by:

$$ME_l \text{ (MJ ME/day)} = \frac{Y \times evl}{k_l} \qquad \text{(Equation 5)}$$

Where:

Y = milk yield (kg per day)

= (national milk yield (Appendix 1) × milk yield monthly proportion (Appendix 4))/number of days in the month

evl = as determined in equation 4 (MJ ME/kg)

k_l = The efficiency of use of ME for milk production

= 0.019 × Pasture ME content (Appendix 3) + 0.42

2.1.4 Metabolisable energy requirements for conception/gestation

$$ME_c \text{ (MJ ME/day)} = 0.025 \times W_C \times \frac{(E_t \times 0.0201 \times \exp(-0.0000576 \times prg))}{k_c} \qquad \text{(Equation 6)}$$

Where:

W_C = the calf birth weight (kg). This is estimated as 9% of the adult cow's live weight that is updated each year (Appendix 1)

E_t = energy required for the "gravid uterus"

= 10(151.665-151.64*exp(-0.0000576*prg))

prg = number of days the cow has been pregnant (Appendix 5)

K_c = 0.133 (Agricultural Research Council (ARC): 1980).

K_c is the efficiency of conversion of dietary energy to the energy needed for gestation.

Values for coefficients used in the calculation of the term E_t are adopted from ARC (1980) where they were determined for a calf whose birth weight was 40kg at 281 days of gestation. A summary of the net requirements for gestation can be found in CSIRO, 2007. For the calculation of the New Zealand Inventory, calf birth weight has been determined as 9 per cent of cow live weight, and analysis of this from 1990 determines calf birth weight over the time series to be between 40.0 kg and 40.8 kg. This is not significantly different to 40.0 kg that has been used to estimate E_t.

2.1.5 Energy requirements for change in liveweight

a) in non-lactating animals

$$ME_g \text{ (MJ ME/day)} = \frac{(6.7 + R) + (20.3 - R)/[1 + \exp(-6(P - 0.4))]}{k_g} \times LWG \times 0.92$$

= (Equation 7)

Where

R	= adjustment for rate of gain or loss = [EBC/(4 × $SRW^{0.75}$)]-1
EBC	= 0.92 × (LWG × 1000)
SRW	= the standard reference weight in kg. Females 550, castrates 660, bulls 770.
P	= current live weight (Appendix 1)/SRW (maximum value of 1)
LWG	= live weight gain in kg per day
kg	= 0.042 × pasture ME content (Appendix 3) + 0.006

b) in growing lactating animals

$$ME_g \text{ (MJ ME/day)} = \frac{neclw \times LWG}{k_g} \quad \text{(Equation 8)}$$

Where

neclw	=10.1 + 2.47 × cs
cs	= condition score = 6
LWG	= live weight gain in kg per day
k_g	= 0.95 × k_l
k_l	= The efficiency of use of ME for milk production
	= 0.019 × Pasture ME content (Appendix 3) + 0.42

c) in lactating animals which lose weight

$$MEg \text{ (MJME/day)} = \frac{neclw \times 0.84 \times LWG}{k_l} \quad \text{(Equation 9)}$$

Where

neclw	=10.1 + 2.47 × cs
cs	= condition score = 6

LWG = live weight gain in kg per day[a]

k_l = The efficiency of use of ME for milk production

= 0.019 × Pasture ME content (Appendix 3) + 0.42

2.1.6 Additional metabolisable energy expenditure of grazing compared with similar live weight, but housed animals

$$\text{MEgraze (MJ ME/day)} = \frac{((C \times DMI(0.9 - DMD)) + 0.05 \times \frac{T}{GF + 3})W}{k_m} \qquad \text{(Equation 10)}$$

Where:

C = 0.006 (CSIRO, 1990)

DMI = dry matter intake from pasture, 10 kg/d

DMD = dry matter digestibility (Appendix 3)

T = Terrain. For dairy this is 1.0 for level.

GF = availability of green forage (tonnes DM/ha). Assumed to be 3.5 tonnes

W = Animal live weight (Appendix 1)

k_m = Net efficiency of use of ME for maintenance.

= 0.02 × pasture ME content (Appendix 3) + 0.5

2.1.7 Adjustment to total energy requirements for rising 1 year olds

Rising 1 year olds are fed milk or milk powder in their first 2 months and therefore receive their energy from these products. Therefore the total energy requirements need to take this into account for the first two months of life. Also, for the first two months of life a calf does not produce any methane and this also needs to be taken into account. The adjustment for methane is applied directly to the methane value itself (detailed later).

In the New Zealand Inventory emission calculations are carried out by adjusting the total energy requirements for the energy received from milk and milk powder by a value of z_l.

Where for months 2 and 3 (August and September)

z_1 (MJ ME/day) = $(Z_{mp}/d) \times (evl/k_l)$ (Equation 11)

Where:

Z_{mp} = milk (from milk powder) fed to calves

= 200 (kg)

d = number of days of lactation (61 days)

evl = as determined in equation 4 (MJ ME/kg)

k_l = The efficiency of use of ME for milk production

= 0.019 × Pasture ME content (Appendix 3) + 0.42

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[a] Live weight gain for bulls can be found in Appendix 1. No weight gain assumed for adult cows. For all other animals it is determined by a linear trend from 90% of average cow weight to adult cow weight (Appendix 1).

The term Z_{mp} is the amount of milk feed to a calf during these two months. For the dairy industry in New Zealand this generally comes from milk powder.

And for months 1 and 4–12 (July and October–June)

$$z1 = 0$$

2.1.8 Determination of Dry Matter Intake

Dry Matter Intake (DMI) is determined by taking the total energy requirement as outlined in Table 2, and dividing this by the energy content of the pasture.

DMI (kg DM/animal/month)

$$= ME_{total} / \text{Pasture ME content (Appendix 3)} \qquad \text{(Equation 12)}$$

2.2 BEEF

2.2.1 Total maintenance energy requirements

As with dairy cattle, the total energy requirement for beef cattle is made up of various components which depend on the physiological state of the animal. The basic equation was outlined in equation 2. The same components that can make up ME_p for dairy cattle can also make up the ME_p for beef cattle, being ME_l, ME_c and ME_g.

Beef animals which are less than 1 year old do not begin grazing until their fifth month of life. Until that time they are milk fed. As with dairy calves they therefore do not require the same amount of energy for grazing in that year and the total ME requirement needs to be adjusted for the reduced ME_{GRAZE}. This is again done by including a further term, z_1, in the calculations for the total ME requirements.

Each class of beef animal and the specific variables used in the calculation of total ME requirements for each class are outlined in Table 3.

Table 3: Equations for the total ME requirements for each category of beef animal

Beef cattle subcategories	Equation
1. Breeding growing cows 0 – 1	(Basal + 1.1 × MEg + MEgraze) – z_l
2. Breeding growing cows 1 – 2	Basal + 1.1 × MEg + MEgraze
3. Breeding growing cows 2 - 3	Basal + 1.1 × (MEl + MEc + MEg) + MEgraze
4. Breeding mature cows	Basal + 1.1 × (MEl + MEc + MEg) + MEgraze
5. Breeding Bulls – mixed age	Basal + 1.1 × MEg + MEgraze
6. Slaughter heifers 0 – 1	(Basal + 1.1 × MEg + MEgraze) – z_l
7. Slaughter heifers 1 - 2	Basal + 1.1 × MEg + MEgraze
8. Slaughter steers 0 – 1	(Basal + 1.1 × MEg + MEgraze) – z_l
9. Slaughter steers 1 - 2	Basal + 1.1 × ME_g + ME_{graze}
10. Slaughter Bulls 0 - 1	(Basal + 1.1 × MEg + MEgraze) – z_l
11. Slaughter Bulls 1 – 2	Basal + 1.1 × MEg + MEgraze

2.2.2 Basal energy requirements

As for dairy cattle, Equation 3 is used to determine basal energy requirements for beef cattle. For live weight (W) and age (A) in this equation see Appendix 8 and Appendix 2 respectively. Pasture ME content and dry matter digestibility (DMD) for beef cattle are detailed in Appendix 9.

2.2.3 Milk production metabolisable energy requirements

Equations 4 and 5 are used to determine milk production energy requirements for beef cattle. For milk fat (F), milk protein (P) and annual milk yield in these equations see Appendix 8. For proportion of annual milk yield each month see Appendix 4.

2.2.4 Metabolisable energy requirements for conception/gestation

Equation 6 is used to determine energy requirements for beef cattle conception/gestation. Calf weight (W_c) is based on the adult cows weight in Appendix 8 and prg coefficients are found in Appendix 5.

2.2.5 Energy requirements for change in liveweight

Equations 7, 8 and 9 are used to determine the energy requirements for liveweight change in beef cattle. Live weight gain (LWG) is the liveweight change determined by a linear trend from birth weight (equivalent to 9 per cent of average beef cow weight) to liveweight at slaughter (Appendix 8). No weight gain is assumed for adult beef cows. .

2.2.6 Additional metabolisable energy expenditure of grazing compared with similar live weight, but housed animals

For beef cattle, Equation 10 is used to determine the energy requirements for grazing. For terrain (T) the value is 1.5 for undulating. Live weight (W) for beef is worked out by the model for each class.

2.2.7 Adjustment to total energy requirements for rising 1 year olds

Rising 1 year old beef animals are feed milk and milk powder in their first 6 months and therefore receive part of their energy requirement from these products. Therefore the total energy requirements need to take this into account for the first six months of life. Also, for the first two months of life a calf does not produce any methane and this also needs to be taken into account. As with dairy cattle the adjustment for methane is applied directly to the methane value (described later).

For months 3–8 (September–March) equation 5 is used to determine the variable z_l.

Where:

Z = milk fed to calves

$$= (0.67 \times Y) + (0.33 \times Z_{mp}) \quad \text{(Equation 13)}$$

Y = milk yield (kg) (Appendix 8) × calving percentage

Z_{mp} = milk fed to calves from milk powder

= 200 (kg)

Calving percentage = 85%

d = length of lactation (182 days)

evl = equation 4

k_l = The efficiency of use of ME for milk production

$= 0.019 \times$ Pasture ME content (Appendix 9) + 0.42

The term Z indicates that 67 per cent of the milk required by each rising 1 year old comes from its mother, while 33 per cent comes from the dairy industry in the form of milk powder.

And for months 1 – 2 and 9–12 (July–August and April–June)

Z_l = 0

2.2.8 Determination of Dry Matter Intake

Dry Matter Intake (DMI) is determined by taking the total energy requirement as outlined in Table 3, and dividing this by the energy content of the pasture.

DMI (kg DM/animal/month) =

ME_{total}/ Pasture ME content (Appendix 9) (Equation 14)

2.3 SHEEP

As with cattle, the total energy requirement for sheep is made up of various components which depend on the physiological state of the animal. The basic equation was outlined in equation 2. The same components that can make up ME_p for cattle can also make up the ME_p for sheep, with the added component of ME_{wool} to account for the ME requirement for the growth of wool.

As with cattle, lambs do not begin grazing immediately at birth and therefore an energy discount is required to cover the months were the lamb obtains some of its energy from milk. This is again done by including a further term, z_1, in the calculations for the total ME requirements.

Each class of sheep animal and the specific variables used in the calculation of total ME requirements for each class are outlined in Table 4.

Table 4: Equations for the total ME requirements for each category of sheep

Sheep subcategories	Equation
1. Dry ewes	Basal + 1.1 × (ME_{wool}) + ME_{graze}
2. Mature Breeding ewes	Basal + 1.1 × (ME_l + ME_c + ME_{wool}) + ME_{graze}
3. Growing breeding sheep	Basal + 1.1 × (ME_l + ME_c + ME_g + ME_{wool}) + ME_{graze}
4. Growing non-breeding sheep	Basal + 1.1 × (ME_g + ME_{wool}) + ME_{graze}
5. Wethers	Basal + 1.1 × (ME_{wool}) + ME_{graze}
6. Lambs	(Basal + 1.1 × (ME_g + ME_{wool}) + ME_{graze}) – z_l
7. Rams	Basal + 1.1 × (ME_g + ME_{wool}) + ME_{graze}

2.3.1 Basal energy requirements

Equation 3 is used to determine basal energy requirements for sheep. Unlike for cattle, the variable K is 1 for sheep (CSIRO, 2007). Liveweight for each class of sheep is determined by the model using liveweight data inputted for some categories (Appendix 12). The variable for age (A) in this equation is detailed for each class in Appendix 2. Pasture ME content is detailed in Appendix 9.

2.3.2 Metabolisable energy requirements for conception/gestation

For the purposes of determining energy requirements from conception/gestation and milk production the model assumes that if a ewe is pregnant in a month, she is not lactating. Therefore the energy requirements for conception/gestation are only calculated for the months where the number of days pregnant for that month is > 0. In the inventory model calculations it is assumed all lambs are born on 1 September. For a term of 147 days, conception would have happened on the previous 6 April. It is also assumed in the inventory model that all lambs are weaned on 1 December and slaughtered on 1 March the following year. Therefore, the ewe will be pregnant from 6 April to 1 September (147 days) and lactating from 1 September to 30 November (91 days).

The equation for determining the ME requirements for conception and gestation in sheep is very similar to that of cattle (equation 6). However, the coefficients used have been developed specifically for sheep. Therefore the entire equation is written in full here for sheep.

ME_c (MJ ME/day) = $0.25 . W_l \frac{(E_t \times 0.07372 \times \exp(-0.00643 \times prg))}{k_c}$ (Equation 15)

Where:

W_l	= lamb birth weight. When the average lambing percentage is above 100% the lamb birthweight is increased by the same percentage. = (Ewe weight (Appendix 12) × 0.09) × lambing percentage (Appendix 12).
E_t	= 10(3.322-4.979 × exp(-0.00643 × prg))
prg	= number of days pregnant (Appendix 5)
k_c	= the efficiency of ME for conceptus energy gain
	= 0.133 (ARC, 1980).

Values for coefficients used in the calculation of the term E_t are adopted from ARC (1980) where they were determined for a lamb whose birth weight was 4.0 kg at 147 days of gestation. A summary of the net requirements for gestation can be found in CSIRO, 2007. For the calculation of the New Zealand Inventory, lamb birth weight has been determined as 9% of ewe live weight, and analysis of this from 1990 determines lamb birth weight over the time series to be between 4.4 kg and 5.0 kg.

2.3.3 Milk production metabolisable energy requirements

The equation (equation 16) used to estimate the ME requirement for milk production in sheep is taken from the Australian Feeding Standards (CSIRO, 2007). This equation uses variables on milk fat and the number of days of lactation. The milk fat value of 8 per cent for lactating ewes has been suggested as a suitable value by CSIRO (2007) for when experimental data is not available, and is based on earlier measurements.

ME_l (MJ ME/day) = $\frac{Y \times evl}{k_l}$ (Equation 16)

Where:

evl	=0.328 × F + 0.0028 × d + 2.2033	(Equation 17)
F	= milk fat percentage (Appendix 12)	
d	= Number of days of lactation. (122 days)	
Y	= y × lambing percentage (Appendix 12).	
y	= daily milk yield (kg/day) (Appendix 12).	
	= milk yield (Appendix 12) × milk yield monthly proportion (Appendix 4))/number of days in the month	
k_l	= The efficiency of use of ME for milk production	
	= 0.019 × Pasture ME content (Appendix 9) + 0.42	

2.3.4 Energy requirements for change in liveweight

The equation to calculate the ME requirements for change in liveweight in sheep is the same as that used for cattle (equation 7). The standard reference weights (SRW) for sheep are 92 kg for rams, 66 kg for ewes and 80 kg for wethers. The current live weight is determined by the model for all classes based on live weight inputs (Appendix 12). Live weight change for rams is detailed in Appendix 12. No weight change is assumed for adult ewes. For all other sheep classes weight changes are determined by the model as a linear change from initial and final weight.

There are different values for the terms kg depending on the sheep class (sheep classes as detailed in Table 4). For classes 1, 2 and 3, kg = 0.950 × k_l. For classes 4, 5, 6 and 7, k_g = 0.42 × pasture ME content (Appendix 9) + 0.006. The term k_l = 0.019 × Pasture ME content (Appendix 9) + 0.42.

2.3.5 Metabolisable energy requirements for wool growth

CSIRO (2007) notes that from information in ARC (1980) it appears that many of the determinations of k_m and k_g have been made with sheep that grew about 6 grams dry greasy wool per day. Therefore, because k_m and k_g appear to allow for this fleece growth, an ME allowance for fleece in excess of this rate is used. From the CSIRO equations (CSIRO, 2007) the following equation is used.

ME_w(MJ ME/day) = 0.13 × (Fl - 6) (Equation 18)

Where

Fladult	= (fl × 1000) / 365 for sheep above 1 year old
Fllamb	= (fl × 1000) / 365) / 2 for sheep below 1 year old
fl	= greasy fleece weight (kg per head)(Appendix 12)

2.3.6 Additional metabolisable energy expenditure of grazing compared with similar live weight, but housed animals

The calculation used to estimate additional ME expenditure for grazing for cattle (equation 10) is the same as that used for sheep. However, the term C has a value of 0.05, and terrain (T) has the value of 1.5, undulating as for beef cattle. Pasture ME content and dry matter digestibility (DMD) can be found in Appendix 9. The current live weight (W) is determined by the model for all classes based on live weight inputs (Appendix 12).

2.3.7 Adjustment to total energy requirements for rising 1 year olds

Lambs receive milk from their mothers in their first four months and therefore receive their energy from these products. Therefore the total energy requirements need to take this into account for the first four months of life. Also, for the first two months of life a lamb does not produce any methane and this also needs to be taken into account. The adjustment for methane is applied directly to the methane value itself (described later).

As for cattle, total ME requirement is adjusted for the energy received from milk by a value of z_1.

Where for months 3–6 (September–December)

z_1 (MJ ME/day) = Z / d × (evl/k_l) (Equation 19)

Where:

Z	= milk yield (Appendix 12) (kg)
d	= length of lactation (122 days)

evl = as in equation 17

k_l = The efficiency of use of ME for milk production

= 0.019 × Pasture ME content (Appendix 9) + 0.42

And for months 1 – 2 and 7–12 (July–August and January–June)

z_l = 0

2.3.8 Determination of Dry Matter Intake

Dry Matter Intake (DMI) is determined by taking the total energy requirement as outlined in Table 4, and dividing this by the energy content of the pasture.

DMI (kg DM/head/mth)

= calculated MEtotal/ Pasture ME content (Appendix 9) (Equation 20)

2.4 DEER

As for dairy cattle, Equation 3 is used to determine basal energy requirements for beef cattle. For live weight (W) and age (A) in this equation see Appendix 14 and Appendix 2 respectively. Pasture ME content and dry matter digestibility (DMD) for deer are detailed in Appendix 9.

ME_m = the ME requirement for maintenance including grazing

ME_l = ME requirements for milk production

ME_c = ME requirements for conception/gestation

ME_g = ME requirements for live weight gain

ME_{velvet}= the ME requirement for the growth of velvet.

The maintenance energy requirements and the energy requirements for liveweight gain were taken from Bown *et al* (2012) who recommended adopting the CSIRO equations for deer.

Each class of deer animal and the specific variables used in the calculation of total ME requirements for each class are outlined in Table 5.

Table 5: Equations for the total ME requirement for each livestock class of deer

Deer subcategories	Equation
1. Breeding hinds	$ME_m + ME_l + ME_c + ME_g$
2. Hinds < 1 year old	$ME_m + ME_g – z_l × 0.64$
3. Hinds 1-2 years old	$ME_m + ME_c + ME_g$
4. Stags < 1 year old	$ME_m + ME_g – z_l × 0.64$
5. Stags 1 – 2 years old	$ME_m + ME_g + ME_{vel}$
6. Stags 2 – 3 years old	$ME_m + ME_g + ME_{velvet}$
7. Mixed age and breeding stags	$ME_m + ME_g + ME_{velvet}$

2.4.1 Maintenance energy requirements

Equation 3 is used to determine basal energy requirements for Deer. Unlike for cattle, the variable K is 1.4 for deer. Liveweight for each class of deer is determined by the model using liveweight data inputted for some categories (Appendix 14). The variable for age (A) in this equation is detailed for each class in Appendix 2. Pasture ME content is detailed in Appendix 9.

The values for the energy equations used in the inventory for deer are based on Bown *et al* (2012) who recommend the adoption of the equation for ME_{basal} as given in CSIRO (2007).

Where:

K	= 1.4 for deer
S	= 1.0 for females and castrates and 1.15 for stags
W	= liveweight (kg)
A	= age in years
K_m	= net activity of use for ME for maintenance = 0.2 x M/D + 0.5

2.4.2 Energy requirements for live weight gain (ME_g)

Bown *et al*. (2012) recommended that the energy requirements for liveweight gain estimates use the CSIRO (2007) equation for ME_g in deer as applied by Nicol & Brookes (2007).

$$ME_g \text{ (MJ ME/day)} = ((6.7 + R) + (20.3 - R) / [1 + \exp(-6(P - 0.4))]/kg) \times LWG$$

(Equation 21)

Where:

R	= adjustment for rate of gain or loss = $[EBC/(4 \times SRW^{0.75})]-1$
EBC	= 0.92 × LWG in g/d
SRW	= the standard reference weight in kg.
P	= current live weight /SRW (maximum value of 1)
LWG	= live weight gain in kg per day
kg	= 0.042 x pasture ME content + 0.006

Energy requirements for lactation (ME_l)

For months 6– 9 (December through March) for the subcategory breeding hinds ME for lactation is determined by:

$$ME_l \text{ (MJ ME/day)} = \frac{Y \times evl}{k_l} \quad \text{(Equation 22)}$$

Where

Y	= daily milk yield (kg/day)
	= milk yield (Appendix 14) × milk yield monthly proportion (Appendix 4))/number of days in the month
evl	= 5.9 MJ/kg (Bown *et al* (2012))
k_l	= 0.64 (Moe *et al* 1971)

For all other months lactation = 0

2.4.3 Adjustment to total energy requirements for rising 1 year olds

Rising 1 year olds receive milk from their mothers in their first four months and therefore receive their energy from these products. Therefore the total energy requirements need to take this into account for the first four months of life.

As for cattle and sheep, emission calculations are carried out by adjusting the total energy requirements for the energy received from milk by a value of z_l for deer.

For subcategories rising 1 year old hinds and rising 1 year old stags for months 6–9 (December to March).

z_l (MJ ME/day) = Z / d × evl (Equation 23)

Where:

Z = milk yield (kg) (Appendix 14)

d = length of lactation (120 days)

evl = 5.9 MJ/kg (Bown *et al* (2012))

2.4.4 Metabolisable energy requirements for conception/gestation

Energy requirements are calculated on a monthly basis. For the subcategories breeding hinds and rising two year old hinds energy for pregnancy is determined by:

ME_c(MJ ME/day) =0.7 × TF × $W^{0.75}$ (Equation 24)

Where:

TF =Trimester factor (Table 6)

W = live weight

Table 6: Trimester factor used in the determination of ME requirement for conception/gestation for deer

Month	Trimester factor (TF)
July	0.2
August	0.3
September	0.3
October	0.6
November	0.6
December	0.0
January	0.0
February	0.0
March	0.0
April	0.0
May	0.1
June	0.1

2.4.5 Metabolisable energy requirements for velvet production

The ME requirement for velvet production is 0.5 MJ ME/day (Suttie 2012). This is added to the total ME requirements for the deer classes as indicated in Table 5.

2.4.6 Determination of Dry Matter Intake

Dry Matter Intake (DMI) is determined by taking the total energy requirement as outlined in Table 5, and dividing this by the energy content of the pasture.

DMI (kg DM/head/mth)

= calculated ME_{total}/ Pasture ME content (Appendix 9) (Equation 25)

3 Nitrogen excretion

In order to calculate the amount of nitrous oxide from livestock manure, the amount of nitrogen excreted needs to be determined for each species. These values are then used to determine the nitrous oxide emissions (N_2O) for each manure management system and then summed to calculate total manure management N_2O.

Nitrous oxide is reported in the inventory in three different sections.

- Manure that is collected and stored is reported under the Manure Management section.
- Stored manure once it has been applied to pasture is reported under animal waste in the Agricultural Soils section.
- Manure that is deposited directly onto pasture during grazing is reported under animal production.

3.1 DAIRY

Ninety-five per cent of dairy Faecal Dry Matter (FDM) is deposited directly to pasture during grazing and five per cent is collected during the time cows spend in the milking sheds. The following calculations are used to determine nitrogen excreted and then these are proportioned into pasture and storage.

To calculate nitrogen excreted the nitrogen retained in product is subtracted from the nitrogen intake of an animal:

$$N_{ex} \text{ (kg N/month)} = N_i - (N_{rm} + N_{lwg}) \qquad \text{(Equation 26)}$$

N_i (kg N/mth) = Nitrogen intake per month

N_{rm} (kg N/kg milk/mth) = nitrogen retained in milk per month

N_{lwg} (kg N/kg LWG/mth) = nitrogen retained in live weight gain per month

3.1.1 Nitrogen intake

For cattle more than 1 year old to determine nitrogen intake:

$$N_i \text{ (tonnes/mth)} = DMI \times N_d/1000/100 \qquad \text{(Equation 27)}$$

Where:

DMI = kg dry matter intake per month (as previously determined from ME requirements

N_d = nitrogen in diet (Appendix 19)

For cattle less than 1 year old the nitrogen intake needs to be adjusted for the amount of nitrogen consumed in milk during the months of August and September using the term z_3. In order to do this a term z_2 is first determined.

For months 2 and 3 (August and September):

z_2 = milk fed to calf per month

$$= (Z_{mp}/61) \times \text{number of days in month (kg/mth)} \qquad \text{(Equation 28)}$$

Z_{mp} = total milk fed to calf from milk powder (200kg)

Else

z_2 = 0

z_3 = kg of nitrogen per month fed in milk

$= z_2 \times P_{mp}/100/6.25/1000$ (Equation 29)

To determine nitrogen intake for cattle less than 1 year old z_2 is using to determine z_3:

N_i (tonnes N/mth)= $(DMI \times N_d/1000/100) + z_3$ (Equation 30)

Where

DMI = kg dry matter intake per month (as previously determined from ME requirements)

N_d = nitrogen in diet (Appendix 19)

P_{mp} = Protein in milk powder fed to dairy calves (3.66)

3.1.2 Nitrogen retained in milk

The nitrogen retained in milk must be determined for mature milking cows as this nitrogen is not excreted in the animal faeces.

N_{rm} (tonnes N/kg milk/mth) = nitrogen retained in milk

$=Y_m \times P/100/6.25/1000$ (Equation 31)

Where

Ym= milk yield per month (kg/mth)

= milk yield (kg) (Appendix 1) × milk yield monthly proportion (Appendix 4)

P = milk protein (Appendix 1)

3.1.3 Nitrogen retained in live weight gain

Nitrogen retained in the animal through live weight gain and not excreted is determined for growing animals by:

N_{lwg} (tonnes N/kg lwg/mth) = kg nitrogen retain in kg of live weight gain

$= LWG \times N_{bt}/100/1000$ (Equation 32)

Where

LWG= live weight gain (kg per month)

N_{bt}= percentage nitrogen in body tissue (Appendix 1)

3.1.4 Nitrogen in urine and faeces

Nitrogen which is excreted is then split into nitrogen from urine and nitrogen from faeces.

N_u (tonnes N/mth) = nitrogen excreted in urine per month

$= ((10.7 \times N_d) + 34) \times N_{ex}/100$ (Equation 33)

Where:

N_d = nitrogen in diet (Appendix 19)

N_{ex} = total nitrogen in excreta per month (tonnes N/mth)

N_f (tonnes N/mth) = nitrogen excreted in faeces per month

$= N_{ex} – N_u$ (Equation 34)

3.2 BEEF

As 100 per cent of beef graze pastures there are no N_2O emissions from manure management from this source. To calculate nitrogen excreted from beef equation 26 is also used. For cattle more than 1 year old to determine nitrogen intake equation 27 is used with the values for DMI those that were previously determined from ME requirements for beef cattle and the nitrogen in the diet reported in Appendix 19.

3.2.1 Nitrogen intake

For cattle less than 1 year old the nitrogen intake again needs to be adjusted for the amount of nitrogen consumed in milk during the six months of September through to (and including) February. The term z_2 is determined using an equation similar to equation 28, but the variables are slightly different.

z_2 = milk fed to calf per month

= (Z /182) × number of days in month (kg/mth) (Equation 35)

Z = total milk fed to calf (kg)

= (0.67 × Y) + (0.33 × Z_{mp})

Y = milkyield (Appendix 8)

Z_{mp} = milk fed from milk powder (200 kg)

Else:

z_2 = 0

To determine nitrogen intake for cattle less than 1 year old equation 29 is then used with the beef value for z_2 used to determine z_3, DMI that were previously determined from ME requirements for beef cattle and the nitrogen in the diet reported in Appendix 19.

3.2.2 Nitrogen retained in milk

The nitrogen retained in milk must be determined for the beef livestock classes cows 2–3 years old and mature milking cows as this nitrogen is not excreted in the animal faeces. This is determined using equation 31 with the following variables:

Y_m = milk yield (kg/mth) (Appendix 8) × proportion of milk each month (Appendix 4)

P = milk protein (percentage Appendix 8)

3.2.3 Nitrogen retained in live weight gain

Nitrogen retained in the animal through live weight gain and not excreted is determined for growing beef animals using equation 34 and the following variables:

LWG = live weight gain (kg/mth)

N_{bt} = % nitrogen in body tissue (Appendix 8)

3.2.4 Nitrogen in urine and faeces

Nitrogen in urine and nitrogen in faeces is determined using equations 33 and 34 respectively. Nitrogen in the diet for beef animals can be found in Appendix 19.

3.3 SHEEP

As 100 per cent of sheep graze pastures there are no N_2O emissions from manure management from this source. To calculate the monthly nitrogen excreted (Nex):

N_{ex} (tonnes N/month) = $N_i - (N_{rm} + N_{lwg} + N_{wool})$ (Equation 36)

N_i (tonnes N/head/mth) = Nitrogen intake per month

N_{rm} (tonnes N/head/mth) = nitrogen retained in milk per month

N_{lwg} (tonnes N/head/mth) = nitrogen retained in live weight gain per month

N_{wool} (tonnes N/head/mth) = nitrogen retained in wool

3.3.1 Nitrogen intake

Nitrogen intake is calculated separately for sheep under 1 year old and over 1 year old. For sheep more than 1 year old:

N_i (tonnes N/head/mth) = DMI × N_d/1000/100 (Equation 37)

Where

DMI = kg dry matter intake per head per month (as previously determined from ME requirements)

N_d = nitrogen in diet (percentage) (Appendix 19)

For sheep less than 1 year old the nitrogen intake needs to be adjusted for the amount of nitrogen consumed in milk during the months of September through to December (inclusive) using the term z_3 (nitrogen from milk). In order to do this a term z_2 is first determined.

For months 3–6 (September–December):

z_2 (kg milk/mth)= Z / d × number of days in month (Equation 38)

Where:

Z = total milk fed (103 kg)

d = length of lactation (122 days)

Else:

z_2 = 0

z_3 = Nitrogen from milk

= z_2 × P/100/6.25/1000 (Equation 39)

Where:

z_2 = milk fed to lamb per month

P = protein in milk (6 per cent)

Nitrogen intake is then defined as:

N_i = (DMI × N_d / 1000 / 100) + z_3 (Equation 40)

Where:

DMI = kg dry matter intake per month (as previously determined from ME requirements))

N_d = nitrogen in diet (Appendix 19)

z_3 = nitrogen fed in milk (kg/month)

3.3.2 Nitrogen retained in milk

For breeding ewes the nitrogen retained in milk needs to be determined:

N_{rm} (tonnes N/head/mth) = nitrogen retained in milk

$$= Y_m \times P /100/6.25/1000 \quad \text{(Equation 41)}$$

Where:

Y_m = milk yield (kg per head per month)

= annual milk yield (Appendix 12) × milk yield monthly proportion (Appendix 4)

P = milk protein (6 per cent)

3.3.3 Nitrogen retained in wool

Wool data is only collected on a national level. Therefore to determine the nitrogen retained in the wool for each animal class the nitrogen retained in the entire national wool yield is first determined. This is then divided by the total sheep population to obtain nitrogen retained in wool per animal per annum.

N_{wool} (kg N/head/mth)= nitrogen retained in wool (kg N/head/month)

$$= (Wool_{total} \times 0.75 \times Wool_N) / population \quad \text{(Equation 42)}$$

Where:

$Woolt_{otal}$ = National wool yield (kg) (Appendix 12)

$Wool_N$ = Nitrogen in wool (decimal) (Appendix 12)

Population = total population of all sheep classes as determined by the population model from Statistics New Zealand data (Appendix 13)

The per annum value is then adjusted to obtain a per animal per month value.

3.3.4 Nitrogen retained in live weight gain

N_{lwg} (tonnes N/head/mth) = nitrogen retain in live weight gain

$$= LWG \times N_{bt}/100/1000 \quad \text{(Equation 43)}$$

Where:

LWG = live weight gain per month (live weight gain per day value as used for equation 15 multiplied by number of days in the month)

N_{bt} = nitrogen in body tissue (percentage) (Appendix 12)

3.3.5 Nitrogen in urine and faeces

Nitrogen in urine and nitrogen in faeces is determined using equations 33 and 34 respectively. Nitrogen in the diet for sheep animals can be found in (Appendix 19).

3.4 DEER

As 100 per cent of deer graze pastures there are no N_2O emissions from manure management from this source. To calculate the monthly nitrogen excreted (N_{ex}):

$$N_{ex} \text{ (tonnes N/mth)} = N_i - (N_{rm} + N_{lwg} + N_{velvet}) \quad \text{(Equation 44)}$$

N_i (tonnes N/head/mth) = Nitrogen intake per month

N_{rm} (tonnes N/head/mth) = nitrogen retained in milk per month

N_{lwg} (tonnes N/head/mth) = nitrogen retained in live weight gain per month

Nv_{elvet} (tonnes N/head/mth) = nitrogen retained in velvet

3.4.1 Nitrogen intake

As with cattle and sheep, nitrogen intake for deer needs to be calculated differently for animals less than 1 year old and those classes over 1 year old to account for the nitrogen being fed to animals less than 1 year old.

For deer over 1 year old the nitrogen intake is determined by:

$$N_i = DMI \times N_d/1000/100 \qquad \text{(Equation 45)}$$

Where:

DMI = kg dry matter intake per head per month (as previously determined from ME requirements)

N_d = nitrogen in diet (percentage) (Appendix 19)

For deer less than 1 year old the nitrogen calves are fed off their mother during December to March (inclusive). Therefore the adjustment term z_3 (nitrogen from milk) needs to be determined. In order to do this a term z_2 is first determined.

For months 6–9 (December–March):

$$z_2 \text{ (tonnes milk/mth)} = Z / d \times \text{number of days in month} \qquad \text{(Equation 46)}$$

Where:

Z = total milk fed to calf (242 kg)

d = length of lactation (122 days)

Else:

z_2 = 0

z_3 = Nitrogen from milk

$$= z_2 \times P/100/6.25/1000 \qquad \text{(Equation 47)}$$

Where:

z_2 = milk fed to lamb per month

P = protein in milk (0.0366)

Nitrogen intake is then defined as

$$N_i = (DMI \times N_d/1000/100) + z_3 \qquad \text{(Equation 48)}$$

Where:

DMI = kg dry matter intake per month (as previously determined from ME requirements))

N_d = nitrogen in diet (Appendix 19)

z_3 = nitrogen fed in milk (kg/month)

3.4.2 Nitrogen retained in milk

For breeding hinds the nitrogen retained in the milk needs to be adjusted for:

N_{rm} (tonnes N/head/mth) = nitrogen retained in milk

$= Y_m \times P/100/6.25/1000$ (Equation 49)

Where:

Ym = milk yield (kg per head per month)

= annual milk yield per head (Appendix 14) × milk yield monthly proportion (Appendix 4)

P = milk protein (percentage = 3.66)

3.4.3 Nitrogen retained in velvet

For stag classes over 1 year of age (stages 1–2, stags 2–3; and mixed age and breeding stags) the nitrogen retained in velvet needs to be accounted for:

$N_{rvelvet}$ (tonnes N/head/mth) = nitrogen retained in velvet

$= V \times N_v / 1000$ (Equation 50)

Where:

V = Velvet yield (kg/mth)

= annual velvet yield per head (Appendix 14)) × monthly proportion of velvet growth (Table 7)

N_v = nitrogen in velvet (Appendix 14)

Table 7: Proportion of annual velvet growth each month

Month	Deer
July	0
August	0
September	1/3
October	1/3
November	1/3
December	0
January	0
February	0
March	0
April	0
May	0
June	0

3.4.4 Nitrogen retained in live weight gain

N_{lwg} (tonnes N/head/mth) = nitrogen retain in live weight gain

$= LWG \times N_{bt} / 100 / 1000$ (Equation 51)

Where:

LWG = live weight gain per month (live weight gain per day value as used for equation 21 multiplied by number of days in the month)

N_{bt}= nitrogen in body tissue (per cent) (Appendix 14)

3.4.5 Nitrogen in urine and faeces

Nitrogen in urine and nitrogen in faeces is determined using equations 33 and 34 respectively. Nitrogen in the diet for deer animals can be found in (Appendix 19).

3.5 OTHER LIVESTOCK SOURCES

Nitrous oxide emissions from the minor species are calculated by multiplying population date by nitrogen excretion (N_{ex}) values (Table 8). New Zealand-specific Nex values are not available for horses, a IPCC default emission factor is used to calculate nitrogen excretion from horses.

Table 8: Default values for nitrogen excreted (N_{ex})

Species	N_{ex} (kg/head/year)	Reference
Goats	10.6-12.1*	Lassey, 2011
Swine	9.0-10.8*	Hill, 2012
Horses	25.0	IPCC default - Table 4.20 Revised 1996 IPCC guidelines
Mules and asses	25.0	IPCC default - Table 4.20 Revised 1996 IPCC guidelines
Broilers	0.39	Fick *et al*., 2011
Layers	0.42	Fick *et al*., 2011
Turkeys	0.60	Fick *et al*., 2011
Ducks	0.60	Fick *et al*., 2011
Breeding chickens	0.42	Fick *et al*., 2011
Other poultry (eg geese, guinea fowl, emus, ostriches)	0.60	IPCC default - Table 4.20 Revised 1996 IPCC guidelines
Alpaca	12.6	New Zealand specific value

* Value is for 2009

For goats, a New Zealand specific N_{ex} value was estimated by Lassey, 2011 as 10.6 kg N/head/year in 1990 and 12.1 N/head/year in 2009. Values for all other years are interpolated by the proportion of milking goats in the total goat population. Hill 2012, estimated a nitrogen excretion rate for New Zealand swine of 10.8 Kg N/head/year for 2009, estimates for all other years are proportional to changes in typical animal mass.

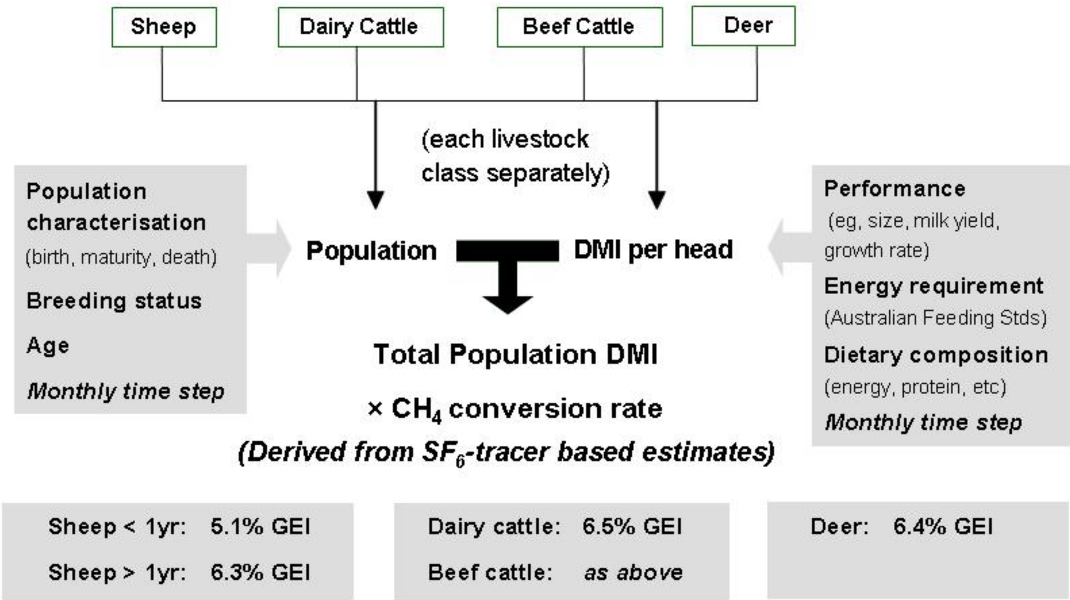
There is no IPCC default value available for N_{ex} for alpacas. Therefore, this was calculated by assuming a default N_{ex} value for alpacas for all years that is equal to the per head value of the average sheep in 1990 (ie, total sheep emissions/total sheep population). The alpaca N_{ex} factor is not indexed to sheep over time because there is no data to support the kind of productivity increases that have been seen in sheep. Sheep were used rather than the IPCC default value for ‘other animals’ as the literature indicates that alpacas have a nitrogen intake close to that of sheep, and no significant difference in the partitioning of nitrogen (Pinares-Patino *et al*, 2003). Therefore, using the much higher default value for “other animals” would be overestimating the true N_{ex} value for alpacas.

4 Enteric fermentation

Methane (CH_4) is a by-product of digestion in ruminants, for example, cattle and some non-ruminant animals such as swine and horses. Within the agricultural sector, ruminants are the largest source of CH_4 as they are able to digest cellulose. The amount of CH_4 released depends on the type, age and weight of the animal, the quality and quantity of feed, and the energy expenditure of the animal.

Using the dry matter intake and population data calculated by New Zealand's tier 2 Inventory model the amount of CH_4 emitted per animal is calculated using CH_4 emissions per unit of feed intake (Figure 1).

Figure 1: Schematic diagram of how New Zealand's emissions from enteric fermentation are calculated



Note: GEI is the gross energy intake and DMI is the dry-matter intake.

Enteric methane (EM) production from cattle (dairy and beef), sheep and deer have been identified through Intergovernmental Panel on Climate Change (IPCC) tier 1 calculations as key sources of greenhouse gas emissions for New Zealand. Therefore, the tier two Inventory model developed by Clark *et al* (2003) is used to calculate these key sources.

4.1.1 Methane emissions per unit of feed intake (CH4 conversion rate)

There are a number of published algorithms and models of ruminant digestion for estimating CH_4 per unit of feed intake. The data requirements of the digestion models make them difficult to use in generalised national inventories and none of the methods have high predictive power when compared against empirical experimental data. Additionally, the relationships in the models have been derived from animals fed indoors on diets unlike those consumed by New Zealand's grazing ruminants.

Since 1996, New Zealand scientists have been measuring CH_4 from grazing cattle and sheep using the SF_6 tracer technique (Lassey *et al*, 1997; Ulyatt *et al*, 1999). New Zealand now has one of the largest data-sets in the world of CH_4 emissions determined using the SF_6 technique on grazing ruminants. To obtain New Zealand-specific values, published and unpublished data on CH_4 from New Zealand were collated and average values for CH_4 from different categories of livestock were obtained. Sufficient data was available to obtain values for adult dairy cattle, sheep more than one year old and growing sheep (less than one year old). Measurements using open-circuit respiration chamber techniques that provided complete gas balances were conducted to further confirm the SF_6 tracer technique.

4.2 DAIRY

The total production of methane for dairy cattle can be determined using the following equation.

$$\text{Methane (tonnes } CH_4\text{/animal/month)} = \text{DMI} \times 21.6 / 1000 \qquad \text{(Equation 52)}$$

The value of 21.6 is the CH_4 emitted per unit of intake obtained from experiments on New Zealand dairy cows (g CH_4/kg intake) (methane conversion rate). It equates to a loss of 6.5% of gross energy assuming that the feed has an energy concentration of 18.45 MJ/kg and gross energy is 55.6 MJ/kg.

For months 2 (August) and 3 (September) for animals 0–1 year old CH_4 are set at 0.

The annual CH_4 for dairy cattle (Gg) for all regions and subcategories can be calculated as:

$$\text{E (Gg } CH_4\text{/year)} = \sum_{month,class,region} (n_{month,clas,region} \times M_{month,class,region}) \times 10^{-6} \qquad \text{(Equation 53)}$$

E = total methane emissions for all dairy cows (Gg CH_4/year)

n = population for each class in each region (national dairy population totals by class Appendix 6)

M = total methane emission for each class in each region (equation 54)

The factor of 10^{-6} is needed to convert annual CH_4 from the each dairy class in units of kg CH_4/animal/year to Gg CH_4/animal/year.

4.3 BEEF

The total production of methane for beef cattle is calculated using equation 54 as for dairy cattle. The only difference is that for beef cattle, for months 3 (September) and 4 (October) for animals 0–1 year old, the CH_4 is set at 0.

4.4 SHEEP

The total production of methane can be determined by the following equations for sheep less than and more than 1 year of age.

Adult sheep (> 1 year old)

$$\text{Meth (tonnes } CH_4\text{/head/mth)} = (\text{DMI} \times 20.9 / 1000) \qquad \text{(Equation 54)}$$

Young sheep (< 1 year old)

$$\text{Meth (tonnes } CH_4\text{/head/mth)} = (\text{DMI} \times 16.8 / 1000) \qquad \text{(Equation 55)}$$

The value of 20.9 and 16.8 are the values for the methane conversion rate obtained from experiments on New Zealand sheep (g CH_4/kg DM intake). It equates to a loss of 6.5% of gross energy assuming that the feed has an energy concentration of 18.45 MJ/kg and gross energy is 55.6 MJ/kg.

For the subcategory of growing breeding sheep, and growing non breeding sheep the first 6 months their life the methane yield used is that for young sheep (16.8) and for the last six months of their life the methane yield used is that for adult sheep (20.9).

For the subcategory of lambs no methane is produced in the first 2 months of life and therefore for these two months methane is set to 0.

The annual methane emissions for sheep (Gg) for all sheep classes can be calculated as

$$E\ (Gg\ CH_4/year) = \sum_{month,class} (n_{month,clas} \times M_{month,class}) \times 10^{-6} \quad \text{(Equation 56)}$$

E = total methane emissions for all sheep (Gg CH_4/year)

n = population for each sheep class (determined by the population model using inputted population data (Appendix 13))

M = total methane emission for each class (equations 54 and 55)

The factor of 10^{-6} is needed to convert annual CH_4 emissions from the each sheep class in units of kg CH_4/animal/year to Gg CH_4/animal/year.

4.5 DEER

As with cattle and sheep, total production of methane (g CH_4/head/month) is determined by multiplying the total dry matter intake and multiplying this by the methane conversion rate. An average of the adult cow and adult ewe value (21.25g CH_4/kg DMI) is assumed to apply to all deer.

$$M = (DMI \times 21.25/1000) \quad \text{(Equation 57)}$$

Where:

$$DMI\ (kg\ DM/head/mth) = \text{calculated } ME_{total} / \text{Pasture ME content} \quad \text{(Equation 58)}$$

Pasture ME content is a weighted average of ME content of feed on dairy and beef-sheep land (Suttie 2012). In 1990 46 per cent of the deer herd was grazed on land use classes used for dairy, and the remaining 54 per cent of the deer herd were grazed on land classes used for sheep and beef grazing. Over time the deer herd has grazed less on dairy land and more on land used for sheep and beef. From 2010 onwards it is assumed only 10 per cent of the deer herd remains on dairy land, and 90 per cent on sheep and beef land (Suttie 2012). The pasture ME content for deer in 1990 and the current year are shown in appendix 9.

Total annual deer methane production (Gg) for all subcategories can be calculated as

The annual methane emissions for deer (Gg) for all classes can be calculated as

$$E\ (Gg\ CH_4/year) = \sum_{month,class} (n_{month,clas} \times M_{month,class}) \times 10^{-6} \quad \text{(Equation 59)}$$

E = total methane emissions for all deer (Gg CH_4/year)

n = population for each deer class (determined by the population model using inputted population data (Appendix 15))

M = total methane emission for each class (equation 57)

The factor of 10^{-6} is needed to convert annual CH_4 emissions from the each deer class in units of kg CH_4/animal/year to Gg CH_4/animal/year

4.6 OTHER LIVESTOCK SOURCES

Methane produced from enteric fermentation from all other livestock is calculated using the tier 1 method. Table 9 shows the other livestock categories which are calculated in New Zealand and their emission factors and the reference for background information on the emission factors.

Table 9: Enteric fermentation methane emission factors used for all other species

Species	Methane (kg CH_4/head/year)	Reference
Goats	10.6 (1990) -12.1 (2009)*	Lassey, 2011
Swine	1.08	Hill, 2012
Horses	18.0	IPCC default - Table 4.3 *Revised 1996 IPCC guidelines*
Mules and asses	10.0	IPCC default - Table 4.3 *Revised 1996 IPCC guidelines*
Poultry (eg geese, guinea fowl, emus, ostriches etc)	Not estimated	IPCC default - *Table 4.3 Revised 1996 IPCC guidelines*
Alpaca	8.0	New Zealand specific value

A tier 1 approach is adopted for minor livestock such as goats, horses, alpaca and swine using either IPCC default emission factors (horses and alpaca) or New Zealand-derived values (swine and goats). These minor species comprised 0.2 per cent of total enteric CH_4 emissions in 2010.

4.6.1 Horses

In the absence of data to develop New Zealand emissions' factors, the IPCC default value is used to determine emissions from enteric fermentation from horses.

4.6.2 Swine

New Zealand uses a country specific emission factor of 1.08 CH_4/head/year (Hill, 2012). This is based on the lower gross energy (GE) value of feed fed to swine in New Zealand.

4.6.3 Goats

A country specific emission factor for enteric fermentation of 7.4 kg CH_4/head/year for 1990 and 8.5 kg CH_4/ head/year for 2009 based on the differing population characteristics for those two years (Lassey, 2011) is used. From 1990 to 2009 the population declined from 1.06 million goats to 0.08 million goats. Most of the decline in the herd was in the non-milking goat population. Therefore, for intermediate years between 1990 and 2009 and for 2010 the emission factor was interpolated based on the assumption that the dairy goat population has remained in near constant state over time, while the rest of the goat population has declined.

4.6.4 Poultry

New Zealand does not estimate emissions from enteric fermentation of poultry because there is no IPCC 1996 methodology to estimate emissions from this category

4.6.5 Alpacas

The IPCC default value from the IPCC 2006 guidelines (IPCC, 2006) is based on a study carried out in New Zealand. In the absence of further work carried out on alpacas in New Zealand this value has been used but is yet to be taken on as a country specific value.

These emission factors are then multiplied by the species population (Appendix 16) to obtain total emissions for each species.

5 Manure management calculations

5.1 METHANE

Methane produced from manure is dependant on the amount of faecal dry matter (FDM) contained in the manure. Therefore, the amount of dry matter intake and the digestibility of the pasture influence methane from manure production.

5.1.1 Dairy

Ulyatt (2002a, 2002b) studied methane emissions from dairy cattle for the New Zealand situation.

Calculations are carried out on a monthly time step for each region and dairy subcategory as detailed in Table 1.

$$FDM = DMI \times (1-DMD) \qquad \text{(Equation 60)}$$

Where:

FDM = Faecal dry matter output

DMI = dry matter intake (As previously determined from ME requirements).

DMD = dry matter digestibility (Appendix 3)

It is estimated that 95 per cent of FDM in the New Zealand dairy situation is deposited while grazing in the paddocks while the balance is deposited in the milking shed during milking (Ledgard and Brier, 2004). FDM is therefore separated out into pasture and stored amounts.

For Pasture:

$$M = (FDM \times MMS) \times Y_m \qquad \text{(Equation 61)}$$

Where: MMS = proportion of methane management system specific for New Zealand dairy cattle (Appendix 17).

Ym = methane yield = 0.00098198 kg CH_4/kg FDM (Sherlock *et al* 2003 and Saggar *et al* 2003)

For Storage:

$$M = (FDM \times MMS) \times W/1000/d \times Y_m \qquad \text{(Equation 62)}$$

Where: MMS = Proportion of methane management system specific for New Zealand dairy cattle (Appendix 17).

W = water added per kilogram of faecal dry matter (90 litres, Heatly 2001)

d = depth of storage = 4.6 m (McGrath and Mason 2002, 2004)

Y_m = methane yield = 3.27 kg CH_4 m^{-2} yr^{-1} (McGrath and Mason 2002)

5.1.2 Beef

Calculations are carried out on a monthly time step for beef subcategory as detailed in Table 3.

$$FDM = DMI \times (1-DMD) \qquad \text{(Equation 63)}$$

Where:

FDM = Faecal dry matter output

DMI = dry matter intake (As previously determined from ME requirements).

DMD = dry matter digestibility (Appendix 9)

All of New Zealand beef is pasture grazed and therefore 100 % of FDM is deposited while grazing in the paddocks.

$$M = (FDM \times MMS) \times Y_m \qquad \text{(Equation 64)}$$

Where: MMS = proportion of methane management system specific for New Zealand beef cattle (Appendix 17).

Y_m = methane yield = 0.00098198 kg CH_4/kg FDM (Sherlock *et al* 2003, Saggar *et al* 2003)

5.1.3 Sheep

Calculations are carried out on a monthly time step for sheep subcategory as detailed in Table 4.

$$FDM = DMI \times (1\text{-}DMD) \qquad \text{(Equation 65)}$$

Where:

FDM = Faecal dry matter output

DMI = dry matter intake (As previously determined from ME requirements).

DMD = dry matter digestibility (Appendix 9)

All of New Zealand sheep is pasture grazed and therefore 100% of FDM is deposited while grazing in the paddocks.

$$M = (FDM \times MMS) \times Y_m \qquad \text{(Equation 66)}$$

Where: MMS = Proportion of methane management system specific for New Zealand sheep (Appendix 17).

Y_m = methane yield = 0.000691 kg CH_4/kg FDM (Carran *et al* 2003)

5.1.4 Deer

Calculations are carried out on a monthly time step for deer subcategory as detailed in Table 5.

$$FDM = DMI \times (1\text{-}DMD) \qquad \text{(Equation 67)}$$

Where:

FDM = Faecal dry matter output

DMI = dry matter intake (as previously determined from ME requirements).

DMD = dry matter digestibility (Appendix 9)

All of New Zealand deer is pasture grazed and therefore 100 per cent of FDM is deposited while grazing in the paddocks.

$$M = (FDM \times MMS) \times Y_m \qquad \text{(Equation 68)}$$

Where: MMS = Proportion of methane management system specific for New Zealand deer (Appendix 17).

Y_m : methane yield

= 0.000915 kg CH_4/kg FDM (Mean of sheep and cattle)

5.1.5 Other livestock sources

Calculations for methane from manure management for all other livestock sources follow the IPCC default calculations.

$$M = MEF \times N \qquad \text{(Equation 69)}$$

Where:

MEF = manure management emission factor (Table 10)

N = population of non key source livestock species (Appendix 16)

Table 10: Manure management emission factors for tier 1 calculations for methane from manure management from non - key source livestock species

Species	Methane (kg CH_4/head/year)	Reference
Goats	0.18	Table 4.5 Revised 1996 IPCC guidelines
Swine	5.94	Hill, 2012
Horse	2.1	Table 4.5 Revised 1996 IPCC guidelines
Mules and asses	1.14	Table 4.5 Revised 1996 IPCC guidelines
Broilers	0.022	Fick *et al*., 2011
Layers	0.016	Fick *et al*., 2011
Other poultry (eg geese, guinea fowl, emus, ostriches etc)	0.117	Fick *et al*., 2011
Alpaca	0.091	New Zealand specific value assumed to be the same as sheep in1990

5.1.6 Goats and Horses

New Zealand-specific emission factors are not available for CH_4 emissions from manure management for goats and horses. These are minor livestock categories in New Zealand and IPCC default emission factors are used to calculate emissions. All faecal material from goats and horses is deposited directly onto pastures.

5.1.7 Swine

New Zealand uses a country specific emission factor of 5.94 CH_4/head/year (Hill, 2012) for estimating emission from swine manure management. This is based on New Zealand specific proportions of swine faeces in manure management systems.

5.1.8 Poultry

Methane emissions from poultry manure management use New Zealand specific emission factor values. These are based on New Zealand specific volatile solids and proportions of poultry faeces in each manure management system for each production category. The poultry population has been disaggregated into three different categories and the values for each are: broiler birds - 0.022 kg CH_4/head/year; layer hens – 0.016 CH_4/head/year and other 0.117 kg CH4/head/year. The value for other (turkeys, ducks etc) is the IPCC default as further work is being carried out on this category. Until country specific information is available for these categories the IPCC default value will continue to be used.

5.1.9 Alpaca

There is no IPCC default value available for CH_4 emissions from manure management for alpacas. Therefore, this was calculated by assuming a default CH_4 emission from manure management value for alpacas for all years that is equal to the per head value of the average sheep in 1990 (i.e. total sheep emissions/total sheep population). The alpaca emission factor is not indexed to sheep over time because there is no data to support the kind of productivity increases that have been seen in sheep.

5.2 NITROUS OXIDE

Nitrous oxide emissions from livestock are determined by the amount of nitrogen excreted from an animal as well as the storage method in which it is kept. The proportion of manure from each livestock species in each animal waste management system (AWMS) is detailed in Appendix 17. The total nitrogen from each livestock species for each AWMS is summed and the system specific emission factor is applied. Nitrous oxide from the "pasture range and paddock" management system is reported under animal production in the Agricultural soils section and the methodological details for this are outlined in that section.

For each Manure management system (S)

$$\text{Nitrous oxide (Gg } N_2O) = \sum_{(S)} \{ [\sum_T (N_T \times Nex_T \times MS_{(T)})] \times EF_{3(S)} \} \times 44/28/10^6$$

(Equation 70)

Where:

N = number of head of livestock of each livestock species T

N_{ex} = Annual average N excretion per head for each livestock species T

MS(T) = Fraction of total annual excretion that is managed in manure management system for each livestock species T

EF_3(S) = N_2O emission factor for manure management system S.

S = manure management system

The population for dairy, beef, sheep, deer and the minor species are detailed in Appendix 6, Appendix 10, Appendix 13, Appendix 15 and Appendix 16 respectively).

The average annual nitrogen excretion per head for dairy cattle, beef cattle, sheep and deer is determined previously in the nitrogen excretion section. For other minor species the nitrogen excreted per head are detailed in Table 8.

The fraction of total annual nitrogen excretion in each manure management system for each livestock species is detailed in Appendix 17.

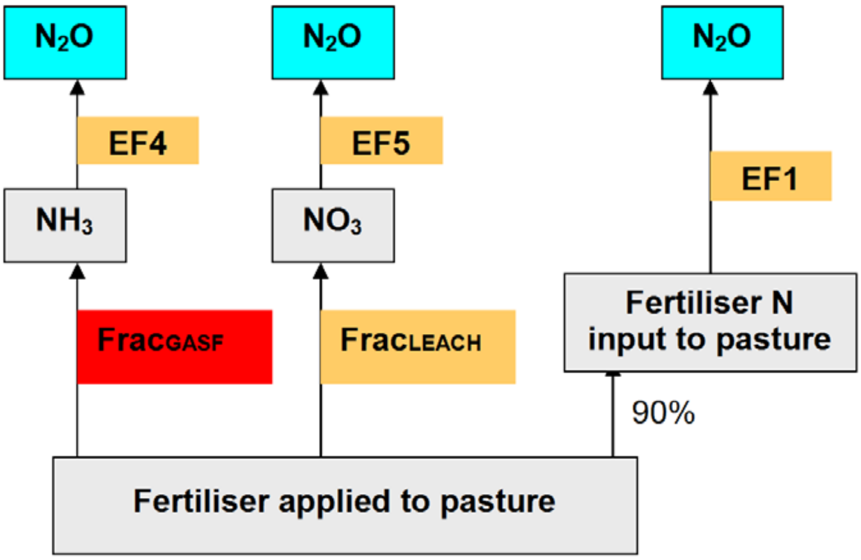
The emission factor for anaerobic lagoons (EF_{3AL}), solid storage and dry lot (EF_{3SSD}) and other manure management systems (EF_{3other}) are detailed in (Appendix 18)

6 Agricultural soils

Emissions from agricultural soils that are reported in the agricultural section of the National inventory consist of nitrous oxide emissions from direct and indirect pathways from the application of nitrogen to the soil. Nitrogen is added to the soil through application of inorganic fertilisers, animal wastes and crop residues, biological processes such as nitrogen fixation, mineralisation and atmospheric deposition, and the leaching of inorganic nitrogen and subsequent denitrification.

Figure 2 shows the pathways in which nitrous oxide can be formed from the application of nitrogen fertiliser.

Figure 2: Flow chart depicting direct and indirect sources of N_2O from fertiliser usage in New Zealand agriculture



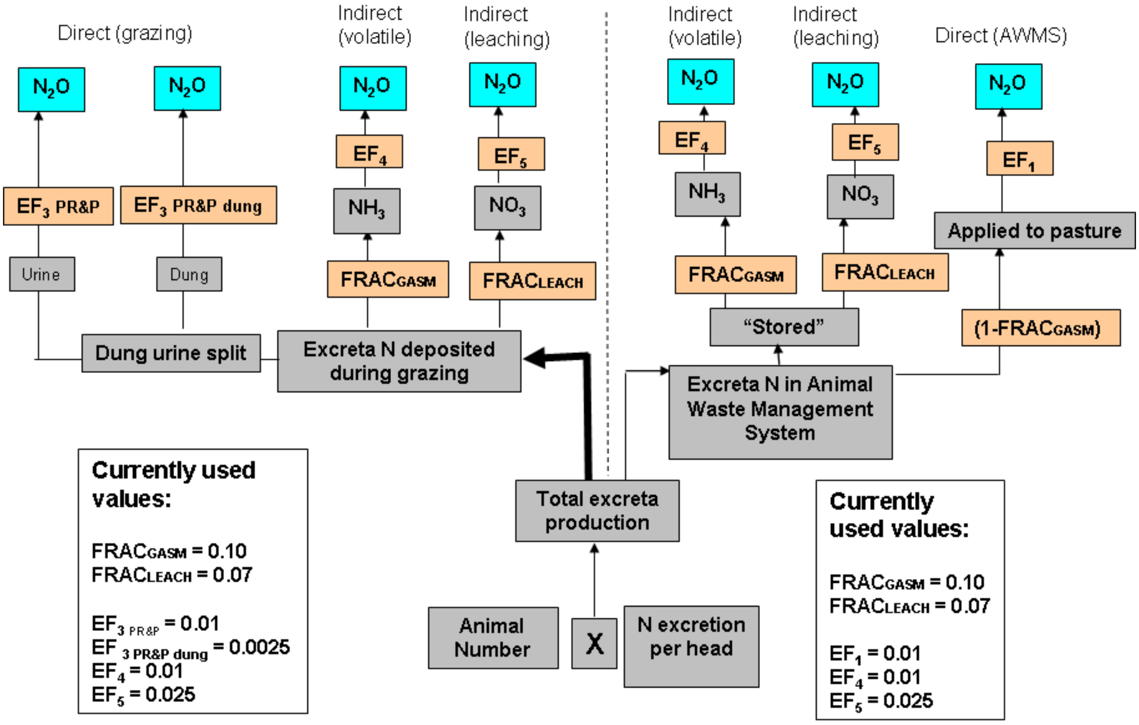
Currently used values:

$Frac_{GASF}$ = 0.10
$Frac_{LEACH}$ = 0.07

EF1 = 0.01
EF4 = 0.01
EF5 = 0.025

Figure 3 depicts the pathways in which nitrous oxide can be formed from the nitrogen excreted from livestock. The majority if the nitrogen excreted follows the left hand pathway with 95 per cent of nitrogen from dairy cattle, 8.9 per cent of nitrogen from swine and 100 per cent of nitrogen from beef cattle, sheep, deer, horses, goats and alpaca. In 2010 4.86 per cent of broilers, 5.8 per cent of layers and 3 per cent of all other poultry are estimated to have manure directly deposited on pasture during grazing. The amount of nitrogen excreted from cattle, sheep and deer is determined in the previous section on nitrous oxide from manure management.

Figure 3: Flow chart of the current IPCC national N_2O inventory methodology for pastoral agriculture in NZ



Note: Emissions from daily spread of swine waste are included with Excreta N deposited during grazing

The 5 per cent of nitrogen from dairy cattle nitrogen which is partitioned into storage, 44.9 per cent of nitrogen from swine, 95.14 per cent from broilers, 94.2 per cent from layers and 97 per cent for all other poultry follow the right hand side of Figure 3. The nitrogen excreted from goats, horses, alpaca, swine and poultry are as detailed in Table 8. Full details of proportions of nitrogen in each animal waste management system (AWMS) for all livestock species are outlined in Appendix 17.

6.1 DIRECT N_2O EMISSIONS

Direct N_2O-N emissions are calculated for each source and then converted to N_2O emissions for reporting purposes by multiplying by 44/28. Nitrous oxide emissions for each source are then added together to produce the total amount of direct N_2O emissions from Agricultural soils.

6.1.1 Synthetic fertiliser application

Anthropogenic N_2O emissions from fertiliser are a relatively small proportion of total N_2O emissions, although still significant. The majority of synthetic N fertiliser used in New Zealand is urea applied to dairy pasture land to boost pasture growth. As depicted in Figure 2 there are three main routes in which the nitrogen can be emitted in the form of nitrous oxide. The majority of it is the direct conversion of nitrogen to N_2O, with two indirect routes being leaching from the soil, and volatilisation of nitrogen into ammonia and oxides of nitrogen (calculated in later sections).

The amount of nitrogen fertiliser applied to soils is collected from FertResearch sales records (Appendix 20). Currently only the total amount of fertiliser sold in New Zealand is available and therefore a breakdown per farming system or region is not possible. This data is then used in the following equations:

$F_{SN} = N_{fert} \times (1\text{-}Frac_{gasf})$ (Equation 71)

N_2O direct from fertiliser (Gg N_2O) = $F_{SN} \times EF_1 \times 44 / 28 \times 10^6$ (Equation 72)

Where:

F_{SN} = annual amount of synthetic fertiliser nitrogen applied to soils after adjusting for the amount that volatilises (kg)

N_{fert} = amount of nitrogen fertiliser applied to soils (kg) (Appendix 20)

$Frac_{gasf}$ = fraction of total synthetic fertiliser emitted as NO_x or NH_3 (Appendix 18)

N_2O direct from fertiliser = nitrous oxide emission direct from the application of nitrogen fertiliser (Gg).

EF_1 = proportion of direct emissions from nitrogen input to soil (Appendix 18)

6.1.2 Animal wastes applied to soils

The majority of animal waste in New Zealand is excreted directly onto pasture, 95 per cent of dairy and 100 per cent of sheep, beef, deer goats, horses and alpaca In 2010 95.14 per cent of waste from broilers, 94.20 per cent of waste from layers and 97.00 per cent of waste from all other poultry is also excreted directly onto pasture. However, some manure is kept in waste systems and then is applied to soils at a later date as an organic fertiliser. There are direct as well as indirect N_2O emissions from this waste (indirect emissions calculated in later sections). The direct emissions calculations do not include animal waste excreted directly onto pasture range and paddock, this is accounted for under animal production.

$F_{AW} = \sum_T N_{AW} \times (1\text{-}Frac_{GASM})$ (Equation 73)

$N_2O_{\text{direct from AW}} = F_{AW} \times EF_1 \times 44 / 28 \times 10^6$ (Equation 74)

Where:

F_{AW} = the total amount of animal manure nitrogen applied to soils from waste management systems (other than pasture range and paddock) after adjusting for the amount which volatilises (kg)

$\sum_T N_{AW}$ = the amount of animal manure nitrogen in each waste management system, other than pasture range and paddock, for all species T

$N_{AW} = N_{ex} \times MS$ (Equation 75)

Where N_{ex} = nitrogen excreted for each species as calculated previously for cattle, sheep and deer, or for other species as detailed in Table 8.

MS = fraction of nitrogen in each management system except pasture range and paddock for each species (Appendix 17)

$Frac_{GASM}$ = Fraction of total animal manure emitted as NO_x or NH_3 (Appendix 18)

EF_1 = proportion of direct emissions from N input to soil (Appendix 18)

6.1.3 Nitrogen fixing crops

The tonnage of nitrogen fixing crops grown in New Zealand is supplied by Statistics New Zealand from their agricultural production survey. It is made up of peas grown for both processing and seed markets as well as lentil production and legume seeds grown for pasture production. Emissions from this subcategory make up a very small amount of New Zealand's agricultural emission (approximately 0.02 per cent of agricultural emissions). A country specific methodology is used to calculate emissions from this section as detailed below. This approach uses harvest index values, root to shoot ratios and N contents of above and below ground residues compiled and used in the OVERSEER® nutrient budget model for New Zealand (Wheeler *et al* 2003). The OVERSEER® model provides average estimates of the fate of nitrogen for a range of pastoral, arable and horticultural systems. OVERSEER® is a source of scientific consensus where nutrient factors are estimated, reviewed and generally agreed among New Zealand experts.

$$TRG_N = AG_N + BG_N \quad \text{(Equation 76)}$$

$$AG_N = dmf \times (CropT/HI\text{-}CropT) \times (1 - Frac_{BURN} - Frac_R) \times N_{AG} \quad \text{(Equation 77)}$$

$$BG_N = dmf \times (CropT/HI) \times N_{BG} \times RatioBG \quad \text{(Equation 78)}$$

$$N_2O_{direct\ N\ fix}\text{-}N = TRG_N \times EF_1 \times 44 / 28 \times 10^6 \quad \text{(Equation 79)}$$

Where:

TRG_N = Total amount of nitrogen returned to soils from nitrogen-fixing crops

AG_N = amount of above-ground nitrogen returned to soils annually through incorporation of crop residues

BG_N = amount of below-ground nitrogen returned to soils annually through incorporation of crop residues

dmf = Dry matter factor

CropT = annual crop production of crops (Appendix 20)

HI = Harvest Index

$Frac_{BURN}$ = fraction of above ground biomass that is burned

$Frac_R$ = fraction of above ground biomass that is removed from the field as product

N_{AG} = above ground nitrogen fraction

N_{BG} = below ground nitrogen fraction

$Ratio_{BG}$ = Root Shoot Ratio

EF_1 = proportion of direct emissions from nitrogen input to soil

Table 11 Parameter values for New Zealand's cropping emissions

Species	HI	dmf	AG_N	$Ratio_{BG}$	BG_N
Wheat	0.46	0.86	0.005	0.1	0.009
Barley	0.46	0.86	0.005	0.1	0.009
Oats	0.3	0.86	0.005	0.1	0.009
Maize grain	0.5	0.86	0.007	0.1	0.007
Field Seed peas	0.5	0.21	0.02	0.1	0.015
Lentils	0.5	0.86	0.02	0.1	0.015
Peas fresh and process	0.45	0.86	0.03	0.1	0.015
Potatoes	0.9	0.22	0.02	0.1	0.01
Onions	0.8	0.11	0.02	0.1	0.01
Sweet corn	0.55	0.24	0.009	0.1	0.007
Squash	0.8	0.2	0.02	0.1	0.01
Herbage seeds	0.11	0.85	0.015	0.1	0.01
Legume seeds	0.09	0.85	0.04	0.1	0.01
Brassica seeds	0.2	0.85	0.011	0.1	0.0081

Curtin *et al*. (2011)

6.1.4 Nitrous oxide from crop residue applied to soil

Crop residues are made up from both N-fixing and non N-fixing crops. The non N-fixing crops in New Zealand include crops such as barley, wheat, maize, oats, onions, squash, potato and some seed crops. The tonnage of these crops is supplied by Statistics New Zealand from their agricultural production survey. Additional information on seed crops is provided by AsureQuality who certify seeds in New Zealand. The contribution of crop residues to the overall agricultural emissions is very small (approximately 0.1 per cent of agricultural emissions).

The methodology used to estimate emission from crop residue is the same methodology for nitrogen fixing crops. However nitrous oxide nitrogen from crop residue is determined rather than nitrous oxide nitrogen from N-fixing crops.

$$N_2O\text{direct crop residue-N} = TRG_N \text{ x } EF_1 \times 44 / 28 \times 10^6 \qquad \text{(Equation 80)}$$

Where:

TRG_N = Total amount of nitrogen returned to soils from crop residue.

6.1.5 Cultivation of histols

Direct N_2O emissions from organic soils are calculated by multiplying the area of cultivated organic soils by an emission factor (EF_2). The area of "organic agricultural soils" cultivated in New Zealand is 160,385 hectares (Dresser *et al.*, 2011). This area includes cultivated organic agricultural soil as delineated by LULUCF and the area of mineral agricultural soils with a peaty layer that are cultivated.

Mineral soils with a peaty layer are included in the definition of organic soils under the Agriculture section as it was determined that these soils will have similar emissions behaviour to that of organic soils. Therefore for the agricultural sector mineral soils with a peaty layer should be included with organic soils when estimating nitrous oxide emission from cultivation of organic soils (Dresser *et al.*, 2011).

The full definition used in the agricultural section for organic soils (plus mineral soils with a peaty layer) is:

- 17% organic matter content (includes slightly peaty, peaty and peat soils of 17 – 30, 30 – 50 and > 50% organic matter content)
- 0.1 m of this depth occurring within 0.3 m of the surface.

Dresser *et al*. (2011) determined that the current assumption that 5 per cent of organic soils (plus mineral soils with a peaty layer) under agricultural pasture are cultivated on an annual bases (Kelliher *et al*., 2002) should be retained until further information has been gathered. This results in 8,019 hectares of "organic agricultural soils" being cultivated annually.

New Zealand uses the IPCC default emission factor (EF_2 equal to 8 kg N_2O-N/kg N) and tier 1 methodology for all years of the time-series. The contribution of organic soils (plus mineral soils with a peaty layer) to the overall agricultural emissions is relatively small (approximately 0.1 per cent of agricultural emissions).

$$N_2O\text{direct organic soils} = FOS \times EF2 \times 44 / 28 \times 10^6 \quad \text{(Equation 81)}$$

Where

F_{OS} = area (hectares) of organic soils which are cultivated annually. Expert opinion has estimated this at 8,019 hectares per year for the entire time series.

EF2 = emission factor for direct emissions from organic soil mineralisation due to cultivation (Appendix 18)

6.1.6 Animal production

Direct emissions from manure deposited during grazing are calculated in this section.

Dairy, beef, sheep and deer

For dairy cattle, beef cattle, sheep and deer the following equations are used to determine N_2O emission separately from urine and dung.

$$\text{For urine } N_2O\ (Gg) = (N \times N_u \times MS) \times EF_{3PR\&P} \times 44/28/10^6 \quad \text{(Equation 82)}$$

$$\text{For faeces } N_2O\ (Gg) = (N \times N_f \times MS) \times EF_{3PR\&P}\ \text{dung} \times 44/28/10^6 \quad \text{(Equation 83)}$$

Where:

N = Population determined by the population model using inputted population data (dairy - Appendix 6; beef - Appendix 10; sheep – Appendix 13; deer - Appendix 15, Other livestock – Appendix 16)

N_u = Nitrogen excreted in urine as previously determine in the nitrogen excretion for each livestock species (kg N per year).

N_f = Nitrogen excreted in faeces (dung) as previously determine in the nitrogen excretion for each livestock species (kg N per year).

MS = fraction of total annual dairy excretion in the pasture range and paddock manure management system (Appendix 17)

$EF_{3\ PR\&P}$ = emission factor for nitrous oxide from urine from dairy cattle, beef cattle, sheep and deer (Appendix 18)

$EF_{3\ PR\&P}$ dung = emission factor for nitrous oxide from faeces/dung from dairy cattle, beef cattle, sheep and deer (Appendix 18)

Dicyandiamide application

Dicyandiamide (DCD) is a nitrification inhibitor which reduces nitrous oxide emissions from animal manure and fertiliser. It is a well researched and environmentally safe and has been demonstrated to reduce N_2O emissions and nitrate leaching in pastoral grassland systems grazed by ruminant animals. There have been 28 peer reviewed, published New Zealand studies on the use and effects of DCD.

The method to incorporate DCD mitigation of N_2O emissions into New Zealand's agricultural inventory is by an amendment to the existing IPCC methodology. It is currently mainly only used on dairy pasture land and therefore is only used to amend the nitrous oxide emissions from dairy cattle.

The peer-reviewed literature on DCD use in grazed pasture systems was critically reviewed and it was determined that on a national basis, reductions in $EF_{3PR\&P}$ of 67 per cent could be made (Clough *et al*, 2008). There has been some research into the effect of DCD on $EF_{3(PR\&P\ DUNG)}$. However, this data is limited and further work needs to be assessed before the incorporating this research into the New Zealand inventory. Therefore DCD is only used to amend $EF_{3PR\&P}$ (and $Frac_{LEACH}$ as discussed later).

The reductions in the emission factors and parameters are used along with the fraction of dairy land treated with DCD to calculate DCD weighting factors.

The appropriate weighting factor is then used as an additional multiplier in the current methodology for calculating indirect and direct emissions of N_2O from grazed pastures. Nitrogen excretion from dairy cattle is determined on a monthly base. DCD is also only applied in the months of May to September inclusive. The weighting factor is therefore only applied to the nitrogen excreted in those months.

The modified equation 84 for nitrous oxide emission from dairy cattle urine in the months May to September is therefore:

For urine N_2O (Gg)

$= (N \times Nu \times MS) \times EF_{3PR\&P} \times \text{DCD weighting factor} \times 44/28/10^6$ (Equation 84)

All other emission factors and parameters relating to animal excreta ($Frac_{GASM}$, EF_4 and EF_5) remain unchanged when DCD is used as an N2O mitigation technology. DCD was found to have no effect on ammonia volatilisation during May to September when DCD is applied. This is supported by the results of field studies (Clough *et al*, 2008, Sherlock *et al*, 2009).

6.1.7 Other livestock sources

Nitrous oxide emissions from the manure of grazing goats, horses, alpaca, and poultry are determined using nitrogen excretion factors as detailed in Table 8 and proportions as detailed in Appendix 17. Population of these minor species is detailed in Appendix 16.

Nitrous oxide from these minor species is not calculated separately for dung and urine and therefore the one emission factor, $EF_{3PR\&P}$, is used Appendix 18.

6.2 INDIRECT N_2O EMISSIONS ASSOCIATED WITH NITROGEN VOLATILISATION FROM SOILS

Nitrogen can be volatised as ammonia or oxides of nitrogen before it is later returned to the soil by rain and then converted to nitrous oxide. This pathway is an indirect pathway.

$$N_2O \text{ (Gg } N_2O \text{ per year)} = [(N_{fert} \times Frac_{gasf}) + (\Sigma T(N(T) \times Nex(T)) \times FracGASM)] \times EF_4 \times 44/28/10^6 \quad \text{(Equation 85)}$$

Where:

N_2O= fraction of N_2O produced from atmospheric deposition

$N_{fer}t$= amount of nitrogen fertiliser applied to soils (kg - Appendix 20)

$Frac_{gasf}$ = Fraction of total synthetic fertiliser emitted as NO_x or NH_3 (Appendix 18)

$N_{(T)}$ = Population of each livestock species (dairy - Appendix 6, beef - Appendix 10, sheep – Appendix 13, deer - Appendix 15 other minor species - Appendix 16)

$N_{ex(T)}$ = nitrogen excreted by each species as calculated previously for dairy cattle, beef cattle , sheep and deer, in the values used for minor species listed in Table 8.

$Frac_{GASM}$ = Fraction of total animal manure emitted as NO_x or NH_3 (Appendix 18)

EF_4 = proportion of nitrogen input that contributes indirect emissions from volatising nitrogen (Appendix 18)

6.3 INDIRECT N_2O EMISSIONS ASSOCIATED WITH NITROGEN LEACHED FROM SOILS

In the New Zealand Inventory, indirect emissions from leaching are calculated on an individual source bases. These sources include 1) nitrogen fertiliser, 2) pasture range and paddock, split out into dairy, beef, sheep, deer, poultry, swine, horses and goats, 3) anaerobic lagoon, split out into dairy, beef, sheep, deer, poultry, swine, horses and goats, and 4) solid storage and dry lot and other waste management systems. The general equation for all of these sources is:

$$N_2O \text{ (Gg } N_2O \text{ per year)} = N_{(S)} \times Frac_{leach} \times EF_5 \times 44/28/10^6 \quad \text{(Equation 86)}$$

Where:

N = nitrogen excreted by each species as calculated previously for dairy cattle, beef cattle , sheep and deer, in the values used for minor species listed in Table 8

$Frac_{leach}$ = Fraction of nitrogen input to soils that is lost through leaching and run-off (Appendix 18)

EF_5 = proportion of nitrogen input that contributes to indirect emissions from leaching nitrogen (Appendix 18)

These values are then summed in order to calculate the total indirect N_2O emissions from leaching of nitrogen.

Dicyandiamide application

DCD also reduces nitrous oxide emission associated with leaching. The peer-reviewed literature on DCD use determined that on a national basis, reductions in $EF_{3PR\&P}$ of 53 per cent could be made (Clough *et al*, 2008).

The reduction in the parameter is used along with the fraction of dairy land treated with DCD to calculate DCD weighting factors.

The appropriate weighting factor is then used as an additional multiplier in the current methodology for calculating emissions of N_2O associated with leaching from grazed pastures.

As with the application of the DCD weighting factor to $EF_{3PR\&P}$, the weighting factor for $Frac_{LEACH}$ is applied to the monthly nitrogen excretion of dairy cattle in the months of May to September inclusive.

The modified equation 85 for nitrous oxide emission from dairy cattle urine in the months May to September is therefore:

$$N_2O \text{ (Gg } N_2O \text{ per year)} = N(S) \times Frac_{leach} \times \text{DCD weight factor} \times EF_5 \times 44/28/10^6 \quad \text{(Equation 87)}$$

7 Prescribed burning of savannah

New Zealand has adopted a modified version of the IPCC methodology (IPCC, 1996). The same equations are used to calculate emissions as detailed in the revised 1996 IPCC Guidelines.

However, instead of using total grassland and a fraction burnt, New Zealand uses statistics of the total area of tussock grassland that has been burnt. Expert opinion concludes that from 1990 to 2004 information on land that has been granted consent (a legal right) for burning, under New Zealand's Resource Management Act (1991) provides the best option for estimating tussock burning (Curtin *et al*., 2011). However, from 2003 this data has become less reliable as burning has become permitted in some regions. Since 2005 however, Statistics New Zealand has started to collect data on tussock grass land burning and it is therefore recommended that this data be used from 2005 (Curtin *et al*., 2011).

Curtin *et al*. (2011) reviewed the methodology and activity data to estimate emissions from tussock burning in New Zealand and recommended changes to the emission factors and the activity data. Analysis of the data showed that the original assumption that only 20 per cent of consented area is burned is likely to be underestimating actual burning. The consents last for five years. Therefore the burning may not actually occur in the year of the burn, and the consenting data do not include illegal burns and accidents. Comparing data from Statistics New Zealand on tussock burning with data on all land consented for burning indicates that the total area consented provides a more accurate estimate and improves the consistency of activity data over the time series.

Current practice in New Zealand is to burn in damp spring conditions, reducing the amount of biomass consumed in the fire. Most of the composition and burning ratios used in calculations are from New Zealand-specific research and have been updated (Payton and Pearce, 2009). Curtin *et al*. (2011) also recommended small modifications to the methodology incorporating new variables from this updated research. The variables carbon content of live biomass and carbon content of dead biomass have been replaced by one variable – Ratio of carbon loss to above-ground biomass loss. The fractions of live and dead material have been combined into one value and only one equation is now required to determine the carbon released from live and dead biomass. One value for the fraction of live and dead material oxidised is now only required.

The following equations are used to estimate the total amount of carbon released during the burning of tussock land in New Zealand.

Table 12 details the emission factors used, appendix 21 details the activity data (area of savanna burned) in New Zealand.

Biomass burned (Gg dam) = area of tussock burned annually × above-ground biomass density (t dm/ha) × fraction actually burned/1000 (Equation 88)

C released biomass (Gg C) = biomass burned (t dm) × Ratio of C loss to above ground biomass × fraction that is live and dead biomass × fraction oxidised (Equation 89)

Total carbon released is then used to estimate CH_4, CO, N_2O and NO_x emissions (Equation 90)

N_2O emissions (Gg N_2O) = C released biomass (Gg C) × Ratio of N:C loss × N_2O emissions factor × 44/28 (Equation 91)

NO_x emissions = total C released × C released biomass (Gg C) × Ratio of N:C loss × NO_x emission factor × 46/14 (Equation 92)

CH_4 emissions = total C released × CH_4 emission factor × 16/12

(Equation 93)

CO emissions = total C released × CO emission factor × 28/12

(Equation 94)

Table 12 Emission factors used to estimate emissions from tussock burning in New Zealand

Description	Factor	Source
Tussock above-ground	28	Payton and Pearce, 2001
Biomass fraction burned	0.356	Payton and Pearce, 2009
Ratio of C loss to above	0.45	Payton and Pearce 2009
Fraction that is live and	1	Curtin *et al*., 2011.
Fraction oxidised	1	Curtin *et al*., 2011.
Ratio of N:C loss	0.45	Payton and Pearce 2009
CH_4 emission factor	0.005	Revised IPCC 1996 Guidelines
CO emission factor	0.06	Revised IPCC 1996 Guidelines
N_2O emission factor	0.07	Revised IPCC 1996 Guidelines
NO_x emission factor	0.121	Revised IPCC 1996 Guidelines

Curtin *et al*., 2011

8 Field burning of agricultural residues

The emissions from burning agricultural residues are estimated using country specific methodology and emission factors (Curtin *et al*., 2011). The methodology is alignment with the 1996 IPCC methodology but utilises country specific parameters. This calculation uses crop production and burning statistics, along with country specific parameters for the proportion of residue actually burnt, harvests indices, dry matter fractions, fraction oxidised, and the carbon and nitrogen fractions of the residue. The country specific values for these parameters are those from the OVERSEER® nutrient budget model for New Zealand (Wheeler *et al*. 2003) and are the same as those used for estimates of emission from crop residues. This provides consistency between the two emissions estimates for crop residue and crop burning.

These parameters were multiplied to calculate the carbon and nitrogen released based on estimates of carbon and nitrogen fractions in different crop biomass. The emissions of CH_4, CO, N_2O and NO_x were calculated using the carbon and nitrogen released and an emissions ratio.

IPCC good practice guidance suggests that an estimate of 10 per cent of residue burned may be appropriate for developed countries, but also notes that the IPCC default values: “are very speculative and should be used with caution. The actual percentage burned varies substantially by country and crop type. This is an area where locally developed, country-specific data is highly desirable” (IPCC, 2000).

For the years 1990 to 2004 the following equations are used for each individual crop, implementing annual crop production values for wheat, barley and oats from Statistics New Zealand. The methodology, parameters and data sources for 2005 onwards are discussed later in this section. Neither legume nor maize crops are burnt in New Zealand but rather crop residue is incorporated back into the soil or harvested for supplementary feed for livestock.

Annual dry matter production (t dm) = Total crop production (t) × dry matter fraction (Equation 95)

Above ground dry matter residue (t dm) = (Annual dry matter production (t dm) / crop-specific Harvest index) - dry matter production (t dm)(Equation 96)

Biomass burned (Gg) = Above ground dry matter residue (t dm) × Area burned as a proportion of total production area × Proportion of residue remaining after any removal × Proportion of remaining residue actually burned / 1000 (Equation 97)

Total Biomass burned is then used to estimate N_2O, NOx, CH_4, and CO.

N_2O = Biomass burned (Gg) × Fraction oxidised × Fraction of N in biomass × N2O emission factor × 44/28 (Equation 98)

NO_x = Biomass burned (Gg) × Fraction oxidised × Fraction of N in biomass × NO_x emission factor × 44/28 (Equation 99)

CH_4 = Biomass burned (Gg) × Fraction oxidised × Fraction of C in biomass × CH_4 emission factor × 16/12 (Equation 100)

CO = Biomass burned (Gg) × Fraction oxidised × Fraction of C in biomass × CO emission factor × 16/12 (Equation 101)

Statistics New Zealand did not collected statistics on crop residue burning prior to 2005. Therefore there were no annual data series for crop residue previously and other methods for obtaining this data were determined.

The recommended proportion of crop area burned for 1990 to 2004 was determined by a farmer survey and is 70 per cent of wheat, 50 per cent of barley and 50 per cent oat crops (Curtin *et al*., 2011). These values are in alignment with Statistics New Zealand data for 2005 – 2007 (2005 being the first year Statistics New Zealand gathered this data) and therefore are applied to the years 1990 - 2004. Values for 2005 onwards are discussed later.

Expert opinion suggests that if crop residue is to be burned, there is generally no prior removal for feed and bedding. Therefore 100 per cent of residue is left for burning after the harvested proportion has been removed (Curtin *et al*., 2011).

The proportion of residue actually burned has been estimated as 70 per cent for the years 1990 – 2004 as this takes into account required fire break areas and differences in the methods used. It is also assumed that farmers will generally be aiming to have as close to complete combustion as possible.

Table 13 Values used to calculate New Zealand emissions from burning of agricultural residues

	Barley	**Wheat**	**Oats**
Fraction of residue actually burnt	0.7	0.7	0.7
Fraction oxidized	0.9	0.9	0.9
Fraction of nitrogen in biomass	0.005	0.005	0.005
Fraction of carbon in	0.4567	0.4853	0.4567

biomass			
Dry matter fraction	0.86	0.86	0.86
Harvest index	0.46	0.46	0.30
Wheat residue remaining in field	1	1	1

Curtin et al., 2011

Table 14 Emission ratios for agricultural residue burning

Compound	Emission ratio
CH_4	0.005
CO	0.06
N_2O	0.007
NO_x	0.121

Source: *Revised IPCC 1996 Guidelines*

A slightly different methodology is used for estimating emissions from agricultural residue burning from 2005 to account for and take advantage of extra data available from this year onwards.

From 2005 data on the total area of crop residues burned in New Zealand is collected. Estimates of the proportion of this total area of wheat, barley and oats is then made using the same proportion for wheat as used for the 1990 – 2004 calculations (70 per cent). The remaining residue burning area is then allocated to barley and oats using the same proportion as the area of each of these crops grown in relation to the total area of barley and oats grown.

The following are the equations used for estimating emissions from agricultural residue burning from 2005 onwards.

Production dry matter area burned (t dm) = Estimated area burned (ha) × Average crop yield (t/ha) × dry matter fraction

(Equation 102)

Above ground dry matter residue (t dm) = (Production dry matter area burned (t dm) / crop-specific Harvest index) – Area of crop burned (t dm)

(Equation 103)

Biomass burned (Gg) = Above ground dry matter residue (t dm) × Proportion of residue remaining after any removal × Proportion of remaining residue actually burned / 1000 (Equation 104)

Total Biomass burned is then used to estimate N_2O, NO_x, CH_4, and CO using the same equations as for 1990 - 2004.

All parameters used in the calculation of emissions from agricultural residue burning for all years are detailed in Table 13 and emission ratios in Table 14.

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10 Appendices

Appendix 1: "Final Inputs" worksheet taken from the dairy inputs file for the Tier Two Inventory program

Live weight of cow is calculated as weighted average of cow weights for three main dairy breeds as reported in New Zealand Dairy Statistics (example see Appendix 8). Calves are assumed to be 9% of an average cow's weight with linear weight gain reaching 90% of an average cow's weight at the first calving (2 yr old). Milk yield, butterfat and protein values from New Zealand Dairy Statistics are adjusted from litres to kg by multiply by a factor of 1.03.

Year	Bull Weight (kg)	Bull Live Weight Change (kg)	Cow Weight (kg)	Milk Yield per cow per year (kg per year)	Butterfat (%)	Protein (%)	Nitrogen retained in tissue (N_{te}) (%)	National annual milk yield (kg per year)
1990	500.00	0.50	447.36	2802.59	4.71	3.48	3.26	7,632,256,223
1991	500.00	0.50	448.56	3024.93	4.75	3.52	3.26	7,990,992,245
1992	500.00	0.50	449.81	3003.44	4.75	3.53	3.26	8,178,170,507
1993	500.00	0.50	450.52	3274.38	4.77	3.53	3.26	9,194,547,559
1994	500.00	0.50	452.44	3081.53	4.74	3.50	3.26	9,226,178,180
1995	500.00	0.50	453.15	3147.42	4.71	3.49	3.26	9,924,546,701
1996	500.00	0.50	447.12	3416.24	4.75	3.52	3.26	10,998,755,116
1997	500.00	0.50	455.36	3407.06	4.68	3.44	3.26	11,310,334,956
1998	500.00	0.50	443.57	3211.00	4.63	3.47	3.26	10,879,890,000
1999	500.00	0.50	454.91	3589.20	4.67	3.52	3.26	11,978,900,000
2000	500.00	0.50	459.66	3797.67	4.70	3.53	3.26	13,312,750,000
2001	500.00	0.50	454.87	3815.19	4.68	3.54	3.26	14,015,210,000
2002	500.00	0.50	458.38	3728.49	4.72	3.59	3.26	14,323,180,000
2003	500.00	0.50	457.12	3828.01	4.76	3.58	3.26	15,036,970,000
2004	500.00	0.50	455.35	3539.98	4.77	3.57	3.26	14,525,673,322
2005	500.00	0.50	454.50	3675.34	4.78	3.59	3.26	15,143,034,389
2006	500.00	0.50	444.32	3767.37	4.81	3.63	3.26	15,588,239,702
2007	500.00	0.50	454.52	3644.53	4.76	3.61	3.26	15,187,207,491
2008	500.00	0.50	445.93	3800.97	4.79	3.64	3.26	16,525,314,663
2009	500.00	0.50	459.29	3685.14	4.81	3.66	3.26	16,977,338,483
2010	500.00	0.50	453.42	3815.95	4.81	3.66	3.26	17,858,996,504
2011	500.00	0.50	462.64	4090.88	4.84	3.71	3.26	19,702,477,306

Appendix 2: Age used for each species category for the calculation of basal energy

Species class	Species Class	Age used
Dairy	Milking cows - mature	4
	Growing heifers 0 – 1	0.5
	Growing heifers 1 – 2	1.5
	Breeding Bulls	4
Beef	Breeding growing cows 0 – 1	0.5
	Breeding growing cows 1 – 2	1.5
	Breeding growing cows	2.5
	Breeding mature cows	4
	Breeding Bulls – mixed age	4
	Slaughter heifers 0 – 1	0.5
	Slaughter heifers 1 - 2	1.5
	Slaughter steers 0 – 1	0.5
	Slaughter steers 1 – 2	1.5
	Slaughter Bulls 0 - 1	0.5
	Slaughter Bulls 1 – 2	1.5
Sheep	Breeding ewes	4
	Dry ewes	4
	Growing breeding sheep	1
	Growing non-breeding sheep	1
	Wethers	4
	Lambs	0.5
	Rams	3
Deer	Hinds 0 -1	0.5
	Hinds 1 -2	1.5
	Mix age breeding hinds	4
	Stags 0 - 1	1
	Stags 1 - 2	1.5
	Stags 2 - 3	2.5

Mix age breeding stags	4

Appendix 3: Monthly digestibility of feed (percentage as a decimal) and energy concentration of feed (MJ ME/kg dry matter) for dairy for entire time series

Collected from a 12 month study in 2001 – 2002 of 10 dairy farms (Ian Brookes, personal communication).

	Monthly Digestibility (Decimal)											
Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Digestibility of feed	0.8366	0.7945	0.7906	0.8048	0.785	0.7377	0.762	0.7362	0.7436	0.7861	0.8121	0.8022
ME of feed	12.582	11.53	11.686	12.007	11.637	10.817	11.084	10.611	10.69	11.329	11.936	11.655

Appendix 4: Proportion of annual milk yield each month

Month	Dairy	Beef	Sheep	Deer
July	0.132922	0	0	0
August	0.139593	0	0	0
September	0.132993	0.167	0.25	0
October	0.128062	0.167	0.25	0
November	0.11298	0.167	0.25	0.1
December	0.103569	0.167	0.25	0.258333333
January	0.092061	0.167	0	0.258333333
February	0.073716	0.167	0	0.233333333
March	0.06876	0	0	0.15
April	0.015344	0	0	0
May	0	0	0	0
June	0	0	0	0

Appendix 5: Cumulative pregnancy array of days pregnant used in ME requirement equations

Month	Dairy	Beef	Sheep	Deer
July	269	238	107	159
August	0	269	138.5	190
September	0	0	0	220
October	0	0	0	251
November	27	0	0	269
December	58	27	0	0
January	89	58	0	0
February	117	89	0	6
March	147	117	0	37
April	177	147	15.5	67
May	208	177	46	98
June	238	208	75.5	128

Appendix 6: Dairy population data from Statistics NZ

Values are June year end. Population models are used to changes values to calendar year. See Clark (2008) for further details. Regional population data is confidential.

		Population Data		
June year end	Dairy Cows & Heifers (1 Year and Over) NOT in Milk or in Calf	Dairy Cows & Heifers (1 Year and Over) in Milk or in Calf	Dairy Cattle Total	Dairy Breeding Bulls
1990	86692	2723288	3440815	31174
1991	87695	2641712	3429427	35315
1992	92274	2722939	3467824	30631
1993	86737	2808030	3550140	29642
1994	120070	2994022	3839184	31430
1995	158391	3153230	4089817	31543
1996	182159	3219548	4165098	32401
1997	187824	3319680	4256000	33409
1998	191708	3388320	4344000	34099
1999	170227	3337486	4316409	39657
2000	194584	3505508	4598136	44447
2001	205432	3673531	4879862	49237
2002	221538	3841553	5161589	54027
2003	149190	3928140	5101603	43707
2004	174124	4103318	5152492	44661
2005	212042	4120176	5087176	38536
2006	234880	4137697	5169557	45190
2007	305727	4167121	5260850	53331
2008	335565	4347657	5578440	56466
2009	331428	4606971	5860776	57480
2010	339286	4680096	5915452	57808
2011	403704	4816190	6174503	66448

Appendix 7: Dairy cow weight determination tool Example for June year end 2010. Data obtained from Dairy NZ Statistics

	Holstein Friesan			Jersey			Holstein Freisian Jersey		
Age	number	weight	Proportion of weight per age class	number	weight	Proportion of weight per age class	number	weight	Proportion of weight per age class
2	194,511	396.70	80.27743888	66,612	317.44	60.32968502	244,165	370.51	85.66831959
3	166,399	481.17	83.29834938	60,118	366.59	62.8784854	199,394	428.02	80.81892189
4	138,738	515.38	74.3892418	51,013	382.37	55.65210676	152,614	450.81	65.15156027
5	126,665	520.08	68.53523748	47,263	405.77	54.71648039	132,605	467.59	58.71675131
6	99,144	533.40	55.01822684	36,273	409.08	42.3358864	98,832	477.63	44.70191057
7	76,863	525.77	42.0436367	30,031	419.67	35.95792754	79,439	480.15	36.11998872
8	61,636	533.15	34.18778795	22,400	425.37	27.18515475	59,090	486.49	27.22229976
9	46,625	531.37	25.7752578	16,149	424.59	19.56285923	41,953	493.33	19.59915974
10	50,617	531.08	27.96684592	20,637	416.25	24.50855716	47,906	489.15	22.19059118
	961198		491.4920228	350496		383.1271426	1055998		440.189503

National herd	% of each breed	
Holstein Friesan	40.0	196.4
Jersey	12.4	47.7
Holstein Freisian Jersey	38.9	171.2
other	8.7	38.1
	100	
National average dairy cow weight		453.42

Appendix 8: "Final Inputs" worksheet taken from the Beef inputs file for the tier Two Inventory program

Live weight of mature cow is calculated using dairy cow weights and slaughter weights (Appendix 11). Breeding bull weights are kept constant. All other weights are converted from slaughter weights as collected and reported by MPI. Calves are assumed to be 9% of an average cow's weight with linear weight gain reaching 90% of an average cow's weight at the first calving (2 yr old). Milk yield is kept constant for beef cows. Butterfat and protein values from New Zealand Dairy Statistics are adjusted from litres to kg by multiply by a factor of 1.03.

Year	Steer live weight (kg)	Heifer live weight (kg)	Bull live weight (kg)	Milking cow live weight (kg)	Breeding bull live weight (kg)	Live weight change breeding bull (kg)	Milk yield per cow per annum (kg/year)	Butterfat (%)	Protein (%)	Nitrogen retained in body tissue (%)
1990	577.87	419.78	565.49	406.34	600.00	0.50	824.00	4.71	3.48	3.26
1991	588.49	423.04	570.10	428.22	600.00	0.50	824.00	4.75	3.52	3.26
1992	584.62	421.88	563.34	423.45	600.00	0.50	824.00	4.75	3.53	3.26
1993	606.26	436.23	589.40	458.31	600.00	0.50	824.00	4.77	3.53	3.26
1994	602.70	437.36	589.08	437.89	600.00	0.50	824.00	4.74	3.50	3.26
1995	593.60	433.89	577.02	450.11	600.00	0.50	824.00	4.71	3.49	3.26
1996	605.48	441.95	612.08	504.88	600.00	0.50	824.00	4.75	3.52	3.26
1997	603.43	439.16	609.57	488.04	600.00	0.50	824.00	4.68	3.44	3.26
1998	589.20	431.42	587.50	468.39	600.00	0.50	824.00	4.63	3.47	3.26
1999	602.67	441.34	600.02	476.36	600.00	0.50	824.00	4.67	3.52	3.26
2000	617.63	441.57	609.63	510.91	600.00	0.50	824.00	4.70	3.53	3.26
2001	612.01	445.61	598.05	493.69	600.00	0.50	824.00	4.69	3.54	3.26
2002	614.04	454.44	608.76	499.70	600.00	0.50	824.00	4.72	3.59	3.26
2003	623.68	458.76	616.06	507.29	600.00	0.50	824.00	4.76	3.58	3.26
2004	622.60	458.41	620.06	519.91	600.00	0.50	824.00	4.77	3.57	3.26
2005	635.52	465.71	628.18	546.39	600.00	0.50	824.00	4.78	3.59	3.26
2006	623.67	461.60	615.15	568.27	600.00	0.50	824.00	4.81	3.63	3.26
2007	607.71	462.91	598.51	483.87	600.00	0.50	824.00	4.76	3.61	3.26
2008	603.08	458.22	599.00	561.96	600.00	0.50	824.00	4.79	3.64	3.26
2009	623.47	474.97	622.28	522.19	600.00	0.50	824.00	4.81	3.66	3.26
2010	608.52	462.35	595.80	525.03	600.00	0.50	824.00	4.81	3.66	3.26
2011	628.08	485.00	615.99	563.24	600.00	0.50	824.00	4.84	3.71	3.26

Appendix 9: Monthly digestibility of feed (percentage as a decimal) and energy concentration of feed (MJ ME/kg dry matter) for all years in the time series for sheep, and beef animals. Average monthly digestibility of feed and energy concentration of feed for 1990 and latest year for deer.

Collected from a national survey of 19 beef and sheep farms conducted between March 2001 and February 2002 (Litherland *et al*, 2002).

	Monthly Digestibility (Decimal)											
Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Sheep and beef												
Digestibility of feed	0.738	0.738	0.777	0.777	0.777	0.681	0.681	0.681	0.661	0.661	0.661	0.738
ME of feed	10.8	10.8	11.4	11.4	11.4	9.9	9.9	9.9	9.6	9.6	9.6	10.8
Deer 1990												
Digestibility of feed	0.783	0.764	0.783	0.790	0.781	0.707	0.718	0.706	0.699	0.719	0.731	0.768
ME of feed	11.6	11.1	11.5	11.7	11.5	10.3	10.4	10.2	10.1	10.4	10.7	11.2
Deer 2011												
Digestibility of feed	0.748	0.744	0.778	0.780	0.778	0.687	0.689	0.687	0.669	0.674	0.676	0.744
ME of feed	11.0	10.9	11.4	11.5	11.4	10.0	10.0	10.0	9.7	9.8	9.8	10.9

Appendix 10: Beef population data from Statistics NZ

Values are June year end. Population models are used to change values to calendar year. See Clark (2008) for further details.

Year	Breeding Cows	Bulls	Total	Heifers	Steers	Bulls
1990	1386418	78965	4593160	376170	581095	382936
1991	1388000	76865	4670569	418723	637721	434053
1992	1418955	76907	4676497	428031	649168	496351
1993	1462787	86448	4757962	425363	580125	573791
1994	1576587	91245	5047848	448888	611463	556127
1995	1616860	88052	5182508	427974	708551	514929
1996	1595548	86676	4852179	492787	807203	473690
1997	1590000	88052	4806000	518288	779084	370000
1998	1443000	79911	4432000	511528	781985	346601
1999	1457413	80709	4643705	454696	610419	368664
2000	1392048	80120	4594029	486969	588710	486552
2001	1326682	79531	4544354	437632	544873	610512
2002	1259190	78945	4491281	401716	467291	626450
2003	1288214	80428	4626617	453700	488552	640547
2004	1263243	67548	4447400	513956	583473	698050
2005	1255255	71305	4423626	509613	596501	577052
2006	1268981	71709	4439136	500590	621409	531330
2007	1195098	80424	4393617	492805	607224	525898
2008	1103603	66336	4136872	500652	647770	553518
2009	1096014	78259	4100718	516472	604933	485606
2010	1117659	70383	3948520	508558	616462	439024
2011	1052822	72379	3846414	480440	595519	431793

Appendix 11: Mature beef cow live weight calculation spreadsheet (For further details see Clark, 2008)

	Dairy cow live weight	Number of cows slaughtered	Number of dairy cows	Number of beef cows	Killing out % dairy cows	Carcase weight of dairy cows	Total weight all carcases	Beef cow replacement rate (%)	Number beef cows killed	Number dairy killed	Total weight dairy carcase	Total weight beef carcase	Av beef cow carcase weight	Av beef cow live weight
1990	446.2	581472	2621378	1355000	42	187.4	104113209	17	230350	351122	65798553	38314656	166.3	390.5
1991	447.4	645694	2723288	1386418	42	187.9	117834423	17	235691	410003	77035679	40798744	173.1	406.3
1992	448.6	611885	2641712	1388000	42	188.4	113866925	17	235960	375925	70823144	43043781	182.4	428.2
1993	449.8	590799	2722939	1418955	42	188.9	109556479	17	241222	349577	66042457	43514022	180.4	423.4
1994	450.5	548110	2808030	1462787	42	189.2	105210372	17	248674	299436	56658927	48551445	195.2	458.3
1995	452.4	657411	2994022	1576587	42	190.0	123991226	17	268020	389391	73994015	49997211	186.5	437.9
1996	453.1	738937	3153230	1616860	42	190.3	141028097	17	274866	464071	88323027	52705070	191.7	450.1
1997	447.1	720733	3219548	1595548	42	187.8	142747668	17	271243	449490	84409180	58338488	215.1	504.9
1998	455.4	875375	3319680	1590000	42	191.3	171918238	17	270300	605075	115721344	56196894	207.9	488.0
1999	443.6	749863	3388320	1443000	42	186.3	142945239	17	245310	504553	93997030	48948209	199.5	468.4
2000	454.9	687825	3337486	1457413	42	191.1	134357518	17	247760	440065	84079830	50277688	202.9	476.4
2001	459.7	596814	3505508	1392048	42	193.1	121038567	17	236648	360166	69532320	51506247	217.6	510.9
2002	454.9	674042	3673531	1326682	42	191.0	133117998	17	225536	448506	85685067	47432931	210.3	493.7
2003	458.4	816993	3841553	1259190	42	192.5	161643304	17	214062	602931	116075385	45567919	212.9	499.7
2004	457.1	853640	3928140	1288214	42	192.0	169172543	17	218996	634644	121845926	47326617	216.1	507.3
2005	455.4	795344	4103318	1263243	42	191.2	158599700	17	214751	580593	111036610	47563090	221.5	519.9
2006	454.5	668020	4120176	1255255	42	190.9	136453282	17	213393	454627	86783681	49669601	232.8	546.4
2007	444.3	709163	4137697	1268981	42	186.6	144305545	17	215727	493436	92082002	52223543	242.1	568.3
2008	454.5	642858	4167121	1195098	42	190.9	125815305	17	203167	439691	83936661	41878644	206.1	483.9
2009	445.9	837919	4347657	1103603	42	187.3	166708922	17	187613	650306	121795102	44913820	239.4	562.0
2010	459.3	826812	4606971	1096014	42	192.9	165000115	17	186322	640490	123552179	41447936	222.5	522.2
2011	453.4	869841	4680096	1117659	42	190.4	171962939	17	190002	679839	129466728	42496212	223.7	525.0

Appendix 12: Final Inputs taken from the sheep inputs file for the tier Two Inventory program

Live weights calculated using slaughter weight and a killing out percentage of 45% for lambs and 40% for ewes and multiplying the slaughter weight of ewes by 1.4 to obtain ram weight. Lamb birth weight is estimated as 9% of adult ewe weight with linear growth rates between birth and 6 months (lamb slaughter age). Hoggets assumed same linear rate as lambs to 6 months of age then at a rate to reach full adult weight at 20 months. Adult wethers assumed to be same weight as adult breeding female. Milk yield, butterfat and protein values are assumed to be constant. For further details see Clark, 2008.

Year	Dry Ewe live weight (kg)	Ram live weight (kg)	Lamb live weight slaughter (kg)	Live weight change ram	Greasy Fleece Weight (kg)	Annual Milk Yield (Kg)	Butterfat (%)	Nitrogen in tissue (%)	Nitrogen in wool (%)	Lambing Percentage rate	National wool yield (kg)
1990	52.30	73.22	31.41	0.05	5.00	103	8	2.6	16.5	94.12	309000
1991	52.86	74.00	32.24	0.05	5.00	103	8	2.6	16.5	96.48	305300
1992	53.00	74.20	32.64	0.05	5.00	103	8	2.6	16.5	97.20	295900
1993	52.56	73.59	34.22	0.05	5.00	103	8	2.6	16.5	91.12	255500
1994	54.26	75.96	34.02	0.05	5.00	103	8	2.6	16.5	98.93	284000
1995	52.55	73.57	32.38	0.05	5.00	103	8	2.6	16.5	103.53	288600
1996	53.45	74.83	33.74	0.05	5.00	103	8	2.6	16.5	100.43	268800
1997	55.38	77.53	35.07	0.05	5.00	103	8	2.6	16.5	108.82	274800
1998	56.20	78.68	34.33	0.05	5.00	103	8	2.6	16.5	110.34	265800
1999	56.55	79.16	34.76	0.05	5.00	103	8	2.6	16.5	101.86	252000
2000	58.11	81.35	36.52	0.05	5.00	103	8	2.6	16.5	108.09	257300
2001	59.85	83.79	36.81	0.05	5.00	103	8	2.6	16.5	107.62	236700
2002	58.23	81.52	37.10	0.05	5.00	103	8	2.6	16.5	103.10	228800
2003	58.64	82.09	37.42	0.05	5.00	103	8	2.6	16.5	114.02	227100
2004	60.52	84.72	38.30	0.05	5.00	103	8	2.6	16.5	108.50	217700
2005	61.77	86.48	38.65	0.05	5.00	103	8	2.6	16.5	112.99	215300
2006	61.80	86.51	38.29	0.05	5.00	103	8	2.6	16.5	114.42	224500
2007	60.26	84.37	37.37	0.05	5.00	103	8	2.6	16.5	110.28	217600
2008	58.32	81.65	36.62	0.05	5.00	103	8	2.6	16.5	108.51	205800
2009	59.97	83.96	38.75	0.05	5.00	103	8	2.6	16.5	111.75	157500
2010	61.90	86.66	39.18	0.05	5.00	103	8	2.6	16.5	117.13	185800
2011	59.63	83.49	39.71	0.05	5.00	103	8	2.6	16.5	104.59	176300

Appendix 13: Sheep population data from Statistics NZ

Values are June year end. Population models are used to changes values to calendar year. See Clark (2008) for further details.

Year	RAMS	EWES-BREEDING	EWESDRY	EWE HOGGS-BREEDING	EWE HOGGS-DRY	RAM HOGGS	WETHER HOGGS	WETHERS	LAMBS	Total Sheep excluding lambs
1990	767.003	44.040.587	1.855.961	1.904.103	10.593.453	880.178	2.968.708	1.590.084	44.775.185	64.600.077
1991	734,540	41,414,031	2,102,176	1,082,028	10,167,504	739,466	2,494,105	1,834,803	39,997,294	60,568,653
1992	684,662	40,453,499	1,246,661	1,643,103	8,938,057	732,058	2,393,466	1,760,686	40,616,456	57,852,192
1993	666,113	36,631,076	1,212,886	3,201,837	8,695,902	712,225	2,328,621	1,712,984	38,716,291	55,161,643
1994	640,588	36,684,469	794,574	1,714,532	8,023,500	697,784	2,324,510	1,688,436	34,990,925	52,568,393
1995	575,207	35,374,952	706,605	1,262,702	7,966,586	667,934	2,142,130	1,602,245	36,243,948	50,298,361
1996	541,283	34,437,986	767,898	1,316,284	8,319,053	608,261	2,106,872	1,274,690	37,017,649	49,466,054
1997	516,374	33,692,996	848,541	1,305,607	8,269,253	578,549	2,160,143	1,246,002	35,148,880	48,816,271
1998	501,556	33,446,796	519,786	944,730	7,956,081	650,937	2,195,511	1,178,509	37,426,000	47,393,907
1999	350,402	33,021,000	241,886	1,891,068	8,882,000	418,500	1,411,536	617,609	38,521,000	46,834,000
2000	344,859	32,355,000	238,060	1,861,154	8,748,000	411,880	1,389,208	607,840	34,853,607	45,956,000
2001	767,626	30,364,254	529,901	1,869,499	6,786,549	916,809	3,092,256	1,352,998	34,840,000	45,679,891
2002	476,268	30,646,410	328,773	2,570,348	6,295,226	568,827	1,918,566	839,457	35,748,000	43,643,874
2003	454,049	29,216,733	313,435	2,450,439	6,001,549	542,291	1,829,064	800,296	32,647,387	41,607,855
2004	433,584	26,784,582	380,693	2,374,210	5,684,176	707,121	2,385,010	822,461	33,247,115	39,571,837
2005	420,945	27,086,569	290,583	2,271,780	5,563,982	726,370	2,449,937	741,947	31,853,940	39,552,113
2006	398,788	26,742,440	301,198	2,662,492	5,364,817	706,796	2,366,229	728,378	33,225,836	39,271,137
2007	382,371	26,418,797	236,632	3,130,399	5,850,583	748,380	2,505,446	607,059	33,809,880	39,879,668
2008	384,896	26,904,995	280,756	3,022,987	5,682,274	755,582	2,529,559	520,545	33,005,451	40,081,594
2009	389,810	26,063,325	286,441	2,524,730	5,551,909	717,699	2,402,730	523,833	31,020,153	38,460,477
2010	344,846	23,485,548	310,820	1,470,068	4,965,623	687,364	2,301,173	522,422	27,888,325	34,087,864
2011	348,318	22,214,044	223,869	1,821,217	4,667,610	610,784	2,044,798	452,950	28,152,100	32,383,589

Appendix 14: Deer inputs (2013)

Year	Hind live weight (kg)	Stag live weight (kg)	Annual Milk yield (kg)	Nitrogen in body tissue (kg)	Nitrogen in velvet (kg)	Velvet yield per animal (kg)
1990	100.00	133.00	204	3.71	0.12	1.94
1991	100.62	135.50	204	3.71	0.12	1.60
1992	101.24	138.00	204	3.71	0.12	1.63
1993	101.86	139.17	204	3.71	0.12	1.94
1994	102.48	140.33	204	3.71	0.12	2.31
1995	103.10	141.50	204	3.71	0.12	2.61
1996	103.71	142.67	204	3.71	0.12	2.85
1997	104.33	143.83	204	3.71	0.12	3.07
1998	104.95	145.00	204	3.71	0.12	2.99
1999	105.57	139.00	204	3.71	0.12	3.37
2000	106.19	147.00	204	3.71	0.12	2.87
2001	106.81	147.50	204	3.71	0.12	3.46
2002	107.43	148.00	204	3.71	0.12	3.22
2003	108.05	145.00	204	3.71	0.12	3.35
2004	108.67	145.00	204	3.71	0.12	2.95
2005	109.29	150.00	204	3.71	0.12	3.80
2006	109.90	150.00	204	3.71	0.12	2.29
2007	110.52	150.00	204	3.71	0.12	3.62
2008	111.14	150.00	204	3.71	0.12	3.16
2009	111.76	150.00	204	3.71	0.12	3.21
2010	112.38	150.00	204	3.71	0.12	3.22
2011	113.00	150.00	204	3.71	0.12	4.00

Appendix 15: Deer population data

Values are June year end.

	HINDS			STAGS				Total population
Year end June	Mixed age breeding	1-2 years old	0-1 years old	Mixed age breeding	0-1 years old	1-2 years old	2-3 years old	
	proportion	proportion	proportion	proportion	proportion	proportion	proportion	numbers
1990	0.44	0.09	0.12	0.11	0.16	0.05	0.02	960,670
1991	0.38	0.07	0.15	0.12	0.19	0.05	0.02	1,111,429
1992	0.39	0.08	0.13	0.16	0.16	0.05	0.02	1,117,079
1993	0.38	0.08	0.14	0.16	0.15	0.05	0.02	1,061,224
1994	0.38	0.08	0.15	0.16	0.14	0.05	0.02	1,211,411
1995	0.37	0.07	0.16	0.16	0.14	0.05	0.02	1,159,844
1996	0.39	0.08	0.12	0.17	0.15	0.05	0.03	1,173,064
1997	0.41	0.08	0.15	0.14	0.16	0.05	0.02	1,332,030
1998	0.42	0.08	0.16	0.11	0.16	0.05	0.02	1,490,994
1999	0.43	0.09	0.18	0.09	0.17	0.05	0.01	1,649,961
2000	0.44	0.09	0.17	0.09	0.17	0.05	0.01	1,640,496
2001	0.45	0.09	0.16	0.08	0.18	0.05	0.01	1,631,034
2002	0.47	0.09	0.15	0.07	0.18	0.05	0.01	1,621,571
2003	0.45	0.09	0.16	0.08	0.18	0.05	0.01	1,662,413
2004	0.43	0.09	0.19	0.08	0.18	0.05	0.01	1,728,779
2005	0.41	0.12	0.17	0.07	0.17	0.05	0.01	1,677,803
2006	0.41	0.10	0.19	0.07	0.18	0.05	0.01	1,561,527
2007	0.43	0.10	0.17	0.07	0.18	0.04	0.01	1,373,687
2008	0.43	0.09	0.18	0.07	0.18	0.04	0.01	1,203,751
2009	0.43	0.10	0.17	0.07	0.19	0.04	0.01	1,127,524
2010	0.43	0.10	0.18	0.07	0.17	0.05	0.01	1,104,732
2011	0.42	0.10	0.18	0.07	0.17	0.04	0.01	1,071,117

Source (Suttie 2012)

Appendix 16: Population numbers for non key source livestock categories

	Goat	Swine	Poultry	Horse	Alpaca and llama	Mules and asses
	(1000s)	(1000s)	(1000s)	(1000s)	(1000s)	(1000s)
1990	1,063	395	8,719	94	0.397	0.141
1991	793	407	8,687	90	0.498	0.141
1992	533	411	8,790	88	0.630	0.141
1993	353	395	9,217	87	0.752	0.141
1994	284	423	9,296	68	0.859	0.141
1995	337	431	10,587	69	1.032	0.141
1996	228	424	11,069	68	1.234	0.141
1997	228	417	10,862	69	1.427	0.141
1998	228	412	11,267	70	1.706	0.141
1999	186	369	11,547	72	2.142	0.141
2000	175	369	11,673	73	2.677	0.141
2001	164	354	12,118	74	3.434	0.141
2002	153	342	12,824	76	4.356	0.141
2003	179	377	13,934	80	6.091	0.141
2004	141	389	14,768	77	7.811	0.141
2005	136	341	15,080	73	10.337	0.141
2006	131	356	14,388	68	12.586	0.141
2007	112	367	14,226	66	14.794	0.141
2008	96	325	14,258	63	15.334	0.141
2009	82	323	13,427	65	15.887	0.141
2010	95	335	13,609	64	15.224	0.141
2011	86	327	13,739	57	14.122	0.141

Appendix 17: Fraction of nitrogen excreted managed in different manure management system - for all livestock species

	Proportion of nitrogen in each management system (MS)							
	Dairy	Beef	Sheep	Deer	Goats	Swine	Poultry	Horse
Pasture Range and Paddock	0.95	1.0	1.0	1.0	1.0	0.09	Broilers – 0.049 Layers – 0.058 Other - 0.3	1.0
Anaerobic lagoon	.05					0.21		
Solid storage and dry lot						0.42		
Daily Spread						0.26		
Other management						0.02	Broilers – 0.951 Layers – 0.942 Other - 0.97	
Reference	Ledgard & Brier 2004	Animals graze outside 365 days/annum	Animals graze outside 365 days/annum	Animals graze outside 365 days/annum	IPCC default table 4-21 1996 IPCC reference manual	Hill 2012	Fick *et al* 2011	IPCC default table 4-21 1996 IPCC reference manual

Appendix 18: Emission factor and fractions used to determine direct and indirect N_2O emissions from Agricultural soils

Parameter	Emission factor or fraction value	Reference
$Frac_{gasf}$	0.1	Sherlock *et al* (2009)
$Frac_{gasm}$	0.1	Sherlock *et al* (2009)
$Frac_{leach}$	0.07	Thomas *et al* (2005)
$Frac_{NCRBF}$	0.03	IPCC Reference manual Table 4.19
$Frac_{NCR0}$ (Oats, Barley and Maize)	0.015	IPCC Reference manual Table 4.19
$Frac_{NCR0}$ (Wheat)	0.012	
$Frac_{NCR0}$ (Potato)	0.014	
$Frac_{R}$	0.45	IPCC Reference manual Table 4.19
$Frac_{BURN}$	0.3	Ministry of Agriculture and Forestry only
$Frac_{BURNL}$ ($Frac_{BURN}$ for legumes)	0.0	Ministry of Agriculture and Forestry (expert
EF_1	0.01	Based on Kelliher and de Klein, 2006
EF_2	8	IPCC GPG Table 4.17
$EF_{3PR\&P\ DUNG}$ =Pasture Range and	0.0025	Luo *et al* 2009.
$EF_{3PR\&P}$ =Pasture Range and Paddock	0.01	Based on Carran *et al* 1995; Muller *et al* 1995;
EF_{3AL} = Anaerobic lagoon	0.001	IPCC GPG Table 4.12
EF_{3SSD} = Solid storage and dry lot	0.02	IPCC GPG Table 4.12
EF_{3OTHER} = Other management	0.005	IPCC GPG Table 4.13 (poultry manure
$EF_{3poultry}$	0.001	Fick *et al*., 2011
EF_4	0.01	IPCC GPG Table 4.18
EF_5	0.025	IPCC GPG Table 4.18

Appendix 19: Nitrogen content (percent) of the diet for dairy, beef, sheep and deer

	Percent Nitrogen in Diet											
Species	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Dairy	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Beef	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Sheep	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Deer												
1990	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32
2011	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07

Appendix 20: Nitrogen fertiliser application and yield of nitrogen fixing and non nitrogen fixing other crops

	Synthetic fertiliser use (kg N per year)	Pea Yield (kg per year)	Lentil Yield (kg per year)	Barley yield (kg per year)	Wheat yield (kg per year)	Maize yield (kg per year)	Oats yield (kg per year)	Potatoes yield (kg per year)	Onions (kg per year)	Sweet corn (kg per year)	Squash (kg per year)	Herbage seeds (kg per year)	Legume seeds (kg per year)	Brassica seeds (kg per year)
1990	59,265,000	81,378,000	3,386,000	434,856,000	188,047,000	161,651,000	78,877,000	467,866,000	162,240,000	57,960,000	73,540,000	28,492,000	6,732,000	1,062,000
1991	61,694,000	89,064,000	3,386,000	382,043,000	180,690,000	183,388,000	57,187,000	456,918,000	168,870,000	63,830,000	80,730,000	28,057,000	9,124,000	1,274,000
1992	70,122,000	99,290,000	5,204,000	318,787,000	191,039,000	163,842,000	57,625,000	445,970,000	175,500,000	69,700,000	87,920,000	28,159,000	8,658,000	978,000
1993	104,095,000	87,268,000	5,018,000	389,523,000	219,414,000	133,069,000	56,793,000	416,944,000	187,620,000	73,100,000	116,580,000	25,704,000	9,331,000	1,314,000
1994	124,131,000	83,898,000	2,712,000	395,476,000	241,853,000	142,768,000	57,718,000	439,840,000	295,740,000	110,520,000	150,180,000	24,439,000	8,347,000	948,000
1995	151,263,000	80,448,000	923,000	302,804,000	245,173,000	160,797,000	38,735,000	494,060,000	341,820,000	147,660,000	136,620,000	33,727,000	8,419,000	1,656,000
1996	153,780,000	70,373,000	923,000	367,181,000	277,014,000	209,710,000	41,217,000	486,040,000	346,320,000	143,360,000	129,320,000	35,771,000	8,588,000	1,322,000
1997	143,295,000	74,637,000	923,000	411,000,000	317,379,000	193,806,000	49,065,000	454,440,000	384,480,000	135,480,000	131,790,000	39,553,000	8,392,000	546,000
1998	155,467,000	97,400,000	940,000	340,000,000	302,100,000	176,148,000	42,223,000	478,860,000	384,480,000	135,480,000	131,790,000	42,062,000	6,268,000	2,204,000
1999	166,819,000	86,400,000	0	304,000,000	320,000,000	197,000,000	41,702,000	560,640,000	384,480,000	135,480,000	140,160,000	39,413,000	5,832,000	1,590,000
2000	189,096,000	100,000,000	0	302,000,000	326,000,000	181,000,000	35,398,000	504,520,000	422,640,000	127,600,000	134,260,000	28,789,000	4,363,000	1,109,000
2001	248,000,000	73,700,000	0	365,000,000	364,000,000	177,000,000	22,394,000	497,300,000	379,950,000	121,700,000	139,360,000	24,543,000	3,476,000	809,000
2002	309,200,000	65,457,000	3,302,000	440,883,000	301,499,000	148,847,000	34,986,000	526,080,000	337,260,000	115,800,000	131,200,000	32,504,000	3,990,000	1,302,000
2003	337,400,000	62,400,000	2,000,000	371,837,000	318,916,000	197,182,000	29,934,000	555,160,000	344,880,000	140,820,000	136,080,000	39,456,000	4,226,000	1,778,000
2004	348,000,000	62,855,983	2,000,000	226,082,000	255,860,000	234,248,000	30,844,000	567,060,000	320,370,000	141,560,000	168,860,000	42,793,000	4,573,000	2,433,000
2005	350,320,000	59,756,320	2,000,000	302,023,000	318,947,000	210,253,000	25,000,000	560,720,000	295,860,000	142,300,000	139,620,000	36,445,000	5,554,000	1,952,000
2006	329,700,000	49,762,320	2,000,000	277,020,000	261,798,000	227,054,000	28,478,000	513,840,000	285,750,000	133,250,000	160,840,000	28,931,000	5,028,000	1,269,000
2007	315,920,000	45,877,320	847,000	335,627,000	344,434,000	185,627,000	27,531,000	516,320,000	275,640,000	124,200,000	155,480,000	34,186,000	3,578,000	2,279,000
2008	328,157,000	47,896,000	1,863,000	408,730,000	343,350,000	205,557,000	25,463,000	486,220,000	273,150,000	112,690,000	132,020,000	43,898,000	3,234,000	2,187,000
2009	279,752,000	42,272,000	1,445,000	435,270,000	403,463,000	237,844,000	33,703,000	501,080,000	270,660,000	101,180,000	136,500,000	42,354,000	4,531,000	2,900,000
2010	332,981,000	58,165,429	3,800,000	308,298,000	444,890,000	188,812,000	47,608,000	521,440,000	289,590,000	86,170,000	132,920,000	28,805,000	3,671,000	1,851,000
2011	360,284,000	53,472,429	4,573,000	367,958,000	383,262,000	210,175,000	28,466,000	579,540,000	308,520,000	71,160,000	129,340,000	39,317,000	3,392,000	2,069,000

Appendix 21: savanna burning activity data 1990 to 2011

	Area of savanna burned 000's hectares
1990	35.4
1991	41.8
1992	31.1
1993	30.8
1994	21.6
1995	13.7
1996	18.1
1997	16.6
1998	8.7
1999	7.4
2000	13.6
2001	10.2
2002	12.0
2003	10.7
2004	10.0
2005	12.6
2006	15.3
2007	23.4
2008	18.3
2009	6.8
2010	10.3
2011	9.7